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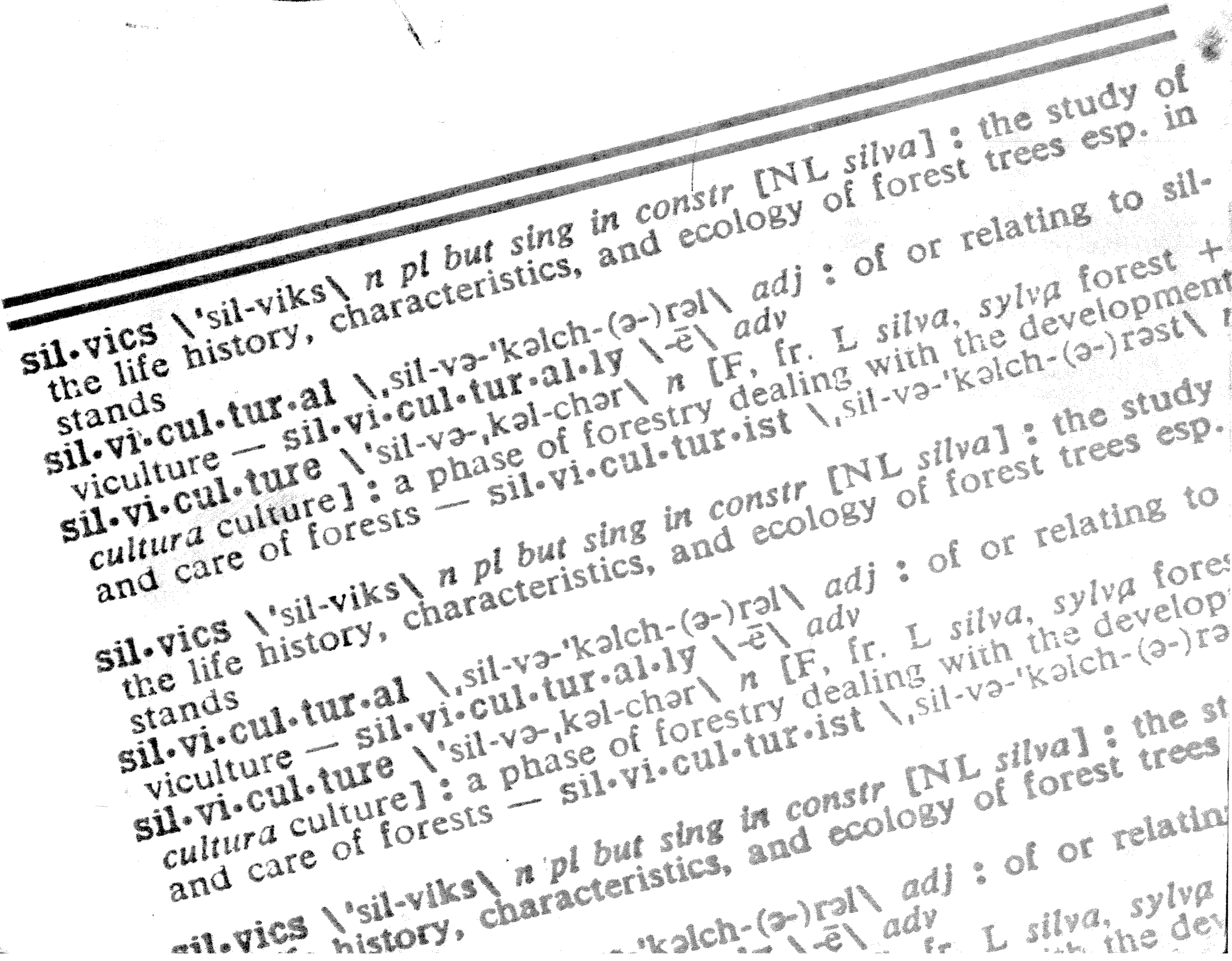
November 6-7, 1980

**Edited by
James P. Barnett**



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FIRST BIENNIAL SOUTHERN SILVICULTURAL RESEARCH CONFERENCE

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Sponsored by:

Southern Forest Experiment Station

Southeastern Forest Experiment Station

Southern Region of the Association of State College and University Forestry Research Organizations

PREFACE

Silvicultural research has been a dynamic force in southern forestry for decades. At the present there is a large group of federal, state, university and industry researchers who are striving to meet the needs of rapidly expanding forestry efforts. Seldom have there been opportunities for those working in the areas of silvicultural research to meet to exchange ideas, coordinate efforts, and establish working relationships. The purpose of this conference was to provide a forum for: exchange among silviculturists, research coordination, continuing education for researchers, review of research in progress, and presentation of new approaches or techniques of general interest.

This first of an intended series of conferences was the outgrowth of coordination meetings between the Southern and Southeastern Forest Experiment Stations that had been held biennially for several years. The late William F. Mann, Jr., suggested at the 1978 coordination meeting that those meetings be replaced by a series of regional conferences that would provide a forum for coordination of research as well as an opportunity for silviculturists to periodically meet. These silvicultural conferences will continue to be scheduled biennially.

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James P. Barnett
Program Chairman

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SILVICULTURAL RESEARCH--A PERSPECTIVE[1]

Philip C. Wakeley[2]

Abstract. Primitive working conditions and meager financing impeded early silvicultural research in the South. The very newness of the field, however, led to rapid and substantial progress; early workers enjoyed "cream to skim". Further, limited staffing necessitated close personal acquaintance with plant material and much cooperative work, both of which yielded large research dividends.

I have been asked to picture silvicultural research in what may seem to some of you rather primitive times. The main points I should like to bring out are: (1) the importance and value, readily apparent in those times, of the researcher's intimate personal acquaintance with the plant material being investigated; and (2) the dividends from starting some studies on spur-of-the-moment inspiration or to seize a unique opportunity, without prior clearance from the Director, the Washington Office, or the League of Nations.

In the light of today's pay scales and costs, the financing of my own first research certainly was primitive. Four years after the Southern Forest Experiment Station's establishment, I began work there on October 16, 1924, as a Temporary Field Assistant at $70 a month plus field expenses. Twenty-five days later I was given permanent appointment as a Junior Forester at $1860 a year plus actual field expenses. As late as 1934 I was detailed to Washington, D. C. for 2 weeks on a $3.00 per diem. Even after 40 years in the Service I never quite made a $15,000 salary; I retired in 1964 at $14,965 a year.

It wasn't that I was treated badly or discriminated against financially. The Southern Station, the Branch of Research, and the U. S. Forest Service itself were poor. My personal diary for January 21, 1927, reads: "Today's paper reports $4,000 a month alimony granted temporarily to the wife of Charlie Chaplin, movie comedian, pending divorce. That's $48,000 a year. The total appropriation of the Southern Forest Experiment Station, with seven permanent and several temporary men, four clerks, four cars, and nine States to cover, is only $39,800."

Prior to my arrival the Station had no vehicles; staff members had to furnish their own cars. In October 1924 we obtained two Model T Fords, to be shared turn and turn about among nearly a dozen permanent and temporary men. In December 1929 I drove one of those original Fords on a 1,200-mile trip to East Texas to see some nurseries. I averaged 8 miles per gallon and was passed on the open road by a horse and buggy. On my return a dealer allowed us $12.50 on the relic toward the price of the Station's first Model A Ford.

Incidentally, those early cars were risky to drive. Twice my car was vandalized, once in North Carolina by three armed men, and a mile from our installation at McNeill, Mississippi, a Department entomologist was shot and killed for driving a similar car. Those were Prohibition Act days, and many country people thought that the "U.S.D.A." on our license plates stood for "U. S. Dry Agent."

EARLY OBSTACLES TO RESEARCH

Many early obstacles to research were financial, like the shortage of automobiles just mentioned. Although we borrowed sufficient good nursery facilities from the Great Southern Lumber Company at Bogalusa, Louisiana, from 1924 through 1931, my "forestation project" was severely handicapped for several years thereafter by lack of a nursery of our own. We borrowed a little greenhouse space in New Orleans one year for germination tests, but had no Station or Forest Service greenhouse until 1934 or 1935. Despite the importance of our seed storage studies and of temperature control to storage, we had no electric refrigerator till Dr. Carl Hartley, of the Bureau of Plant Industry, assigned one for my use about 1931; my first tests of cold storage were made in my domestic ice box at home.

Our shortage of manpower as a result of meager appropriations was not wholly deleterious. It forced us to "swap work" a good deal, and as a result each of us had a beneficial familiarity with most of the Station's program. Nevertheless, dropping one's own work to help with someone else's too often resulted in starting studies without

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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adequate planning, in working on them at other than the best season, in failing to take some data, or in postponing analysis or publication. In February 1933, for example, Wahlenberg and Gemmer tabulated all the Station's natural-reproduction plots, defined the general and particular purposes for which they had been established, and then rated the plots as having their objects "attained", or as "attainable, possibly attainable, or unattainable." They reported many in the last category "largely because of lack of planning".

Until we got our first business manager in September 1929, the Director, to the detriment of planning and other research functions, had to devote far too much of his time to keeping or verifying and to vouching for all the Station's time and property records and accounts. And it was well into the Thirties before we got an editor of our own and ended the nightmare of being edited by mail from Washington.

The passage of the McSweeney-McNary Act in 1928 and the establishment of the Civilian Conservation Corps--the "CCC"--and other New Deal "alphabet agencies" in and after 1933 went far toward mitigating our financial and manpower troubles. By 1936, instead of working alone and virtually without resources, I had four full-time assistants and all the seed supplies, Forest Service nursery space and planting area, day labor, computing help, and supplies and travel money I could use.

There were other than financial obstacles, however.

One was a general assumption, held for several years, that the mild climate of the South would let us work outdoors 9 months of the year and do our office work under fans during the 3 hottest summer months. This assumption led us to take far more data than we could analyze or publish in the time we allowed, and it was decades before we caught up with even our most important work.

Both we and our Washington overhead were untrained amateurs or novices at many phases of administration and procedure--problem selection and analysis, filing, indexing, defining lines of authority. One horrible example will suffice. In 1934 I had to fill in from personal recollection much essential information, such as weather conditions and seedling foliage-development and root length, missing from Hadley's 1924-25 establishment reports on 12 acres of experimental plantations at Bogalusa. He had made out the reports on forms prescribed and required by the Washington Office. The forms had been "edited" by the Station Director in New Orleans and then "annotated" in Washington. In the process, they had been typed in full, recopied, and recopied again (with all four versions carefully preserved) but had never been bound or even stapled. My personal diary for July 24, 1934, notes: "There's short-sightedness and ineptness somewhere in the system that permits such old-maid fussiness, red tape, hindrance, and delay in such an important preliminary phase of investigation as an establishment report--a phase the vital element of which is prompt completion."

A major obstacle to the conduct and completion of planned and scheduled research was the imposition from Washington, usually without warning, of one or another special Service-wide assignment. Our first experience with such assignments was to gather data, following the Mississippi River flood of 1927, for what was ultimately published as 70th Congress House Document 573 on <u>Relation of forestry to the control of floods in the Mississippi Valley</u>. The "flood study" was assigned to us July 6, 1927, and kept every man and girl at the Station occupied, full time and overtime, till August 30 that year. And we were called upon for supplementary information at intervals till October 1928, when I had to take time off to "determine" the total moisture-holding capacity of the forest leaf litter in the lower Mississippi Valley on the basis of less than 4 pounds of litter sent to us by cooperators!

The time it took to write and issue my first major government publication is a good example of the delays caused not only by Service-wide assignments like the flood study, but also by the necessity of continuing one's regular projects without understudies or assistants and of deferring one's regular work to help with projects considered of higher priority.

This publication, <u>Artificial reforestation in the Southern Pine Region</u>, U. S. Dept. Agri. Tech. Bul. 492, was only 114 pages long. It was first proposed to me orally, by Washington Office personnel, in April 1929, when our first experimental plantations were only 6 years old. It was discussed further in November 1929, when I was expected to submit a first draft, within a year, for revision. I jotted down the outline for the bulletin on my own time, at home, on January 25, 1930.

Maintenance of my going studies in seed, nursery, and planting, some work on the "Capper Report" (imposed by Washington), 6 months full time in 1931 and intermittent time thereafter on fire data from Bogalusa for the Director, and more than 2 months in 1932 on the "Copeland Report" (for Washington) all interrupted work on the bulletin. By January 1933 I had only a third of the publication drafted and office personnel had not typed all of that.

The first draft was more than 2 years overdue in Washington. In desperation I offered a recent high-school graduate five cents a half page, double-spaced elite type, to take the rest of the text at dictation and type it up. In 2 weeks I dictated all the rest of the bulletin to her at night, in overtime and at my own expense. By June 8, 1933, I had revised her typing, had a fair copy typed at the office, and had added some completed and some skeleton tables and graphs. We submitted the manuscript to Washington on June 8, 1933, and after a tedious 2-1/2 years of editing and rewriting, the finished bulletin (dated November 1935) came off the press in January 1936. Despite disparaging comment on the bulletin from the Washington Office, the rapidly expanding CCC planting program on the southern National Forests and in several southern States resulted in the practically complete exhaustion of the first printing (3,000 copies, as I recall) in about 3 weeks. A second printing was eventually issued.

Two other early and very serious obstacles to research require mention.

One of these was a practically profession-wide prejudice against fire in the forest, in any form. When I joined the Southern Station staff in late 1924, Project Pf, "Protection, fire" had the highest priority of our six formal lines of work. (My project, "Forestation", had the lowest.) We wasted unconscionable percentages of our meager funds and manpower laying out plots (often without check plots), measuring fire scars, tallying dead seedlings, and taking photographs to "prove" that any and all fire was "bad", instead of the numerous different things that fire actually did. And in several studies, including one very expensive one, we contrasted annual burning with complete exclusion of fire, without ever considering the possible effects of periodic fires.

It was the early or mid-Thirties before a number of circumstances (including my own 1931 study of various burns in the longleaf pine type at Bogalusa) opened our eyes to the potential benefits of prescribed burning. In this field, H. H. Chapman and Herbert L. Stoddard were years ahead of us.

The other major obstacle was our well-nigh universal lack of grounding--at the Southern Station and in Washington--in statistical theory and techniques.

Not one of our Station staff had had any statistics in college. Among the old 1912 to 1914 thinning plots that we had inherited and all plots of all kinds that we had laid out ourselves from 1921 through 1927, there was no single instance of replicated treatment!

A few of us younger men had misgivings in the matter and were buying books--the Station library had none on the subject--and were trying to learn something about statistics by ourselves. I was stimulated by Donald Bruce's comment in April 1926 that "no germination tests he had so far heard of had any sound statistical basis" and that enough similar samples or replications would "permit checking by the method of standard deviation." On March 5, 1928, I laid out the Station's very first replications, five apiece of two soil disinfectants and their untreated checks in our borrowed nursery beds at Bogalusa, and 6 weeks later laid out ten 1-milacre spraying-plot replications and ten 1-milacre checks in dense longleaf reproduction, also at Bogalusa.

In June 1928 L. I. Barrett and I started a staff seminar in statistics, but it never amounted to much. The real break came with Roy A. Chapman's return to the Station in October 1934, after 3 years' intensive training in Washington under Francis X. Shumacher and some priceless contact with R. A. Fisher. Roy revolutionized our experimental design, vastly improved our sampling techniques, taught us analysis of variance, and showed us the immense possibilities in measuring interactions. (In my own work, measurement of interactions sometimes increased by fifty-fold the amount of information obtainable from a given quantity of seed or number of planted trees.) From that time on our publications took on a new cast and, I believe, helped stimulate other Stations to similar progress in statistics.

EARLY RESEARCH ASSETS AND INCENTIVES

Although "trading work" to offset the meagerness of our staff did interrupt our individual studies, as noted under OBSTACLES TO RESEARCH, it did, as also noted there, give us a breadth of information and perspective not always enjoyed by researchers in later, more affluent times.

During my early years on the Southern Station staff a growing interest in the southern pines and later in commercial planting and in the Station's whole program of research brought many of the professionally great to our territory. As the most junior member of the staff I often drove the Model T Ford while a distinguished visitor talked shop with the Director on the back seat or rode in front with me to see better. Later I frequently served as the main guide for such visitors in many different places, but especially over the commercial plantings and natural reproduction and our own experimental plantations and other plots at Bogalusa. The facts and principles learned and the stimulus derived from these visitors[3] were beyond price.

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[3] For the record, they included Dr. George Sudworth of check-list fame, W. W. Ashe, Associate Chief Forester Earle Clapp, H. H. Chapman, Austin Cary, Walter Mulford, Eloise Gerry, Raphael Zon, and Extension Forester W. R. Mattoon, and also Wild Life Specialists Aldo Leopold and H. L. Stoddard. Among our most distinguished foreign visitors up to 1936 were Tor Jonson, Henrik Hesselman, H. G. Champion, and Dr. Franz Heske.

By no means all our help, however, came to us from professionally trained men. We were thrown into contact with, and came to know and appreciate, a host of keenly observant and highly intelligent foremen and day laborers in many phases of commercial forestry work.

Much of the nursery information in my Tech. Bul. 492 and guiding later studies came to me from the Great Southern Lumber Company's nursery foreman, Kenzie Knight. He was an ex-convict with only a second-grade education, but his knowledge of southern pine nursery stock and soils and weeds and other pests was phenomenal.

Milt Miley, a Great Southern planting- and fire-crew foreman, had a little more schooling. He taught me much about the Nantucket tip moth and helped directly with some of my life-cycle caging experiments. (He knew what the moths were because he had tied his wife's dish towel over some infested twigs and "made her wipe the dishes with her apron till the moths come out.")

My own most valuable informant, however, was F. O. ("Red") Bateman, Chief Ranger of the Great Southern Lumber Company, who, in the short space of 12 or 13 years, developed the basic method of planting southern pines still in use today, supervised the successful planting of 28,500 acres, and (even more remarkable) obtained abundant natural reproduction of longleaf pine on 45,000 acres. Although he had had no formal technical training, and indeed had not completed high school, I still consider Red, as I wrote in the Journal of Forest History (1976. 20: 2, 91-99) to have been one of the greatest silviculturists the South has known.

We owed much to a succession of temporary field and laboratory assistants, who contributed many original observations and important suggestions as well as vast amounts of high-quality routine work. Some of these temporary employees later acquired permanent appointments, like Roy Chapman, whose contributions in statistics I have already mentioned, and Mary L. Nelson, whose work with seed made her the best team-mate I ever had in the forestation project.

We owed much of our early progress to our cooperators. The Great Southern Lumber Company at Bogalusa gave us nursery space, planting and other study areas, quantities of seed, occasional work crews, and the coverage of their fire-protection system, and other companies also gave us substantial help. From 1934 on, Region 8 of the U. S. Forest Service assisted our forestation research immensely with nursery and planting space, CCC and other manpower, quantities of seed, and some outright funding. Many State foresters extended similar cooperation to a lesser but still important degree. The Bureau of Plant Industry in Washington (especially through Dr. Carl Hartley), the Forest Products Laboratory, several schools of forestry, and the Boyce-Thompson Institute of Plant Research all helped us with technical information and in some instances with laboratory services.

The essence of cooperation is mutual interest, a free exchange of information, and goodwill. The present Council Tool Company planting bar is a case in point. Over the years the company developed it from an original design by Red Bateman at Bogalusa, with the help of A. D. Read of the Long-Bell Lumber Company (who first added the step), three CCC enrollees (who inspired the substitution of the "T" for the original "D" handle), and myself, who worked out the most efficient dimensions of blade and handle.

INTIMATE ACQUAINTANCE WITH PLANT MATERIAL

In the early days, each of us in charge of a main line of work had to share each stage of investigation with the few understudies or assistants we had, if indeed not carry it out entirely alone. In my case, for example, I collected, extracted, dewinged, and made germination tests of most of my own seed; grew, counted, measured, dug, and packed my own seedlings; and helped plant my own trees and then examined and measured them annually for the first 5 or 10 years in the field. The resulting intimate acquaintance with our plant material was one of our greatest assets in our early research.

By 1926 we were aware that the Nantucket pine tip moth, *Rhyacionia frustrana* Comst., caused serious damage to young planted loblolly and shortleaf pines. I believe it was in the fall of that year that Dr. Tragard, a visiting Scandinavian entomologist, opined that the insect must have a 2-year life cycle. This I could not believe, because I had found overwintering pupae in the tips of 10-month-old loblolly pine seedlings in the nursery. To prove my point I began, on planted trees, a series of caging experiments that ultimately proved that in southern Louisiana the tip moth had four generations a year (1935. So. Forest Exp. Sta. Occas. Paper 45, 8 pp.).

In my annual remeasurements of trees in experimental plantations, it had grown upon me not only that all young southern pines were multinodal, but also that the first internode formed each year was distinctly longer than the later ones. This observation led, ultimately, to the concept of the "five-year intercept" technique for evaluating site quality in stands less than 20 years old (Wakeley, 1954. Proc. Third Annual Forestry Symposium, School of Forestry, La. State Univ., pp. 32-33. Wakeley, P. C. and Marrero, Jose. 1958. Jour. Forestry 56: 332-336, illus.).

In 1932, in the process of thinning an overdense natural stand of longleaf pine seedlings for Dr. L. J. Pessin, then Field Assistant Linc Ellison noted that the needle fascicles of small longleaf seedlings might be either 2-needled or 3-needled, instead of consistently 3-needled as the text-books said. He called the phenomenon to my attention and later published a paper on it. In turn, I subsequently discovered that when longleaf seedlings infected with brown spot needle blight regressed from the 3-needled to the 2-needled habit, they were usually past saving by spraying with fungicide. This finding was of direct value in scheduling the spraying or prescribed burning of longleaf pine plantations.

Laboratory Assistant Mary L. ("Polly") Nelson's epoch-making discovery of the role of light in the germination of southern pine seeds arose from similar intimate acquaintance with plant material. She was running germination tests on "mats" of moist acid peat in square glass dishes with plain glass lids, 1000 seeds per test in four dishes holding 250 seeds each. Because of lack of space she was stacking the dishes four deep, and soon noticed that the seeds in the top dish germinated sooner and more completely, sometimes far more completely, than the comparable seeds in the three dishes below. By further tests she proved conclusively that differences in light accounted for the phenomenon. She published the results in the ephemeral Southern Forestry Notes No. 41, 1940, and they were soon picked up and quoted all over the world. The technique used at the Macon Seed Laboratory traces back directly to her finding.

SPUR-OF-THE-MOMENT STUDIES

During my first 10 years at the Southern Station I and others often learned more from studies undertaken on our own initiative, from sudden inspiration, and not approved in advance by higher authority, than we did from regularly scheduled major efforts prescribed by the Director, various advisory bodies, or Washington overhead. To keep the record straight, let me say that we usually fitted such studies into gaps in regular scheduled work, with little or no extra travel, and that we carried many of them out on "contributed"--that is, on unpaid--overtime.

For example, Hadley, under whom I did my first planting at Bogalusa, had been directed to study spacings of slash and longleaf pines, and fall versus spring planting, dibble versus mattock planting, and pruned versus unpruned roots of these two species and loblolly pine. In December 1924 we laid out 12 acres of Great Southern Lumber Company land for these studies. When we had fitted all the prescribed tests into the layout, we had an acre and a half left over. Hadley said "What shall we do with them?"

I was less than 2 months on the job, but, in measuring seedlings for Hadley in some of his nursery tests, I had been greatly impressed by variations in size, foliage, and degree of dormancy of the seedlings in even the best and most uniform beds. I said "Let's compare first- and second-grade seedlings and cull seedlings of slash and loblolly pines."

We did, and, except for the spacing tests, the grades were the only treatments we put in that winter that produced any significant differences in survival or growth. With some refinements made during the next few years, those initial seedling grades developed into those still in use today.

Again, H. H. Chapman's 1922 publication of "Sonderegger pine" as probably a loblolly X longleaf hybrid, plus my own discovery of Sonderegger seedlings in the longleaf pine seed beds at Bogalusa, led me to try to authenticate the cross by making it artificially. Controlled application of loblolly pollen to bagged longleaf "flowers" in 1928 and 1929 failed, but controlled application of slash pine pollen to longleaf "flowers" in 1929 yielded a fine lot of hybrids. I understand that some of them are still growing in the arboretum at Placerville, California. E. J. Schreiner, in U. S. Dept. Agri. 1937 Yearbook Separate 1599, 1938, has described them as only the third or fourth authentic artificial pine hybrids, and certainly the first such southern pine hybrids, ever made.

Both in EARLY RESEARCH INCENTIVES and in INTIMATE ACQUAINTANCE WITH PLANT MATERIAL I have already mentioned studies of the life cycle of the Nantucket tip moth. I conceived these studies personally and independently. They were unapproved in advance, carried out entirely in connection with other travel, and done almost wholly on contributed time. My wife made the cages required out of cloth I paid for myself. The studies not only placed our knowledge of the insect itself in correct perspective but yielded me two fairly widely quoted publications and a pleasant trip (though at tourist rates, to be sure) to the Fourth International Entomological Congress in Ithaca in 1928.

One of my first assignments at the Southern Station was making germination tests of pine seed already stored 1 or more years in "paper, sealed wax paper, or sealed glass", both with and without prior sterilization with formaldehyde solution. In 1924 and for several years thereafter, all correspondence from Washington continued to stress container and sterilization tests, apparently on the assumption that infection by micro-organisms or contact with the air might be causing the serious to complete deterioration within 1 year that characterized the seed of all species.

Memories of my college course in plant physiology led me to wonder whether storage <u>temperature</u> might not have some effect. Negotiations with Boyce Thompson Institute in 1927 led to trials of storage at 25°-30° F., with room-temperature checks, and in 1928 I tried storage at about 55° F. in my ice-box at home. The results were revolutionary; we found we could keep even the sensitive seed of longleaf pine viable for several years.

A number of further leads made Polly Nelson and me turn our attention to the effect of seed moisture content on keeping quality. We stored seed of several species at a wide range of moisture contents both under refrigeration and at room temperature, and found that, of the two, low seed moisture content was even more important than low temperature (Mary L. Nelson. 1938. Southern Forest Expt. Sta. Occasional Paper 78, 19 pp.). Seed of one 1931 slash pine lot I had stored at low temperature and by chance at low moisture content still germinated 69 percent after 45 years.

To conclude, intimate acquaintance with one's material and some freedom to do things with it on impulse certainly paid off--in dollars and cents, and in good, clean fun besides.

SILVICULTURAL RESEARCH - CURRENT APPRAISAL AND RESEARCH NEEDS [1]

F. Bryan Clark [2]

Abstract.--The need for and challenge of silvicultural research in the South is great. Projections for forestry research needs in the South suggest a 66-percent increase in silvicultural research by 1985. It is important to choose priorities carefully, coordinate our efforts, and take full advantage of opportunities to cooperate.

Phil Wakeley has provided a picture of the history of silviculture research. My goal is to provide a picture of silvicultural research in the future.

Silvicultural research has center stage in the South. The soils, climate, topography and the inherent growth potential of the tree combine to form conditions for excellent growth. So much so that southern forests are expected to produce half the Nation's wood products needs by the year 2000, and, at the same time, provide quantities of livestock forage, clean water, wildlife habitat and recreational opportunities. Southern timberlands have been producing 30 percent more pine sawtimber than has been harvested. Yet, the average acre of forestland in the South is capable of growing two or more times than present. The South offers a unique challenge to forestry research because most of the gain in forest goods and services must come from small, nonindustrial ownerships that control 72 percent of the forest land base. It is essential that we give serious thought and positive attention to problems that keep these lands from growing more wood faster.

Obviously to meet future demands for forest goods and services and still produce the needed timber supplies, we must increase timber production per acre. In the South, this translates into the culture of about 70 pines and hardwoods. Adding to the challenge of meeting these objectives is the need to foresee and provide practical answers to new problems. For example, insect and disease control measures will become more important as intensive management increases. Wildfires will become more costly as forest investments rise and plantations of genetically improved trees are established. Maintenance of soil productivity and water quality will demand higher priorities for future research, as will impacts for wildlife and recreation usage.

Forestry research efforts continue to be closely coordinated and jointly planned through a system of regional and national planning groups sponsored by the U. S. Department of Agriculture. The Forest Service research program undergoes regular assessment in cooperation with the state Agricultural Experiment Stations, forestry schools, and research users. Research priorities change as new technologies develop and as new regional and national problems arise.

I am sure that most of you have been involved in past planning efforts. The RPA Assessment and Program documents (1980); Pine Reforestation Task Force Report for Southern Forests (1977); Report of the Forest Resources Task Force for Long-Range Planning in Timber Management, "Forest Resources Research Needs in Timber Management," (1974); Intensive Culture on Industrial Forest Lands and Future Wood Supplies; Trends, Expectations, and Needs - a report prepared for TAPPI (1976); A research Development and Application Plan, "Improved Use and Management of Eastern Hardwoods" (1980); and the

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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Southern Region Reference Document - National Program of Research for Forests and Associated Rangelands (1977) are major cooperative efforts. I have used this last document as a basis for these comments. Its sponsors and the sponsors of this conference are the same.

Projections for forestry research needs in the South suggest a 66-percent increase in the timber management research program by 1985. This is more than double projected increases for other research program areas.

A review of the program of this conference provides a good picture of current southern silvicultural research priorities and direction. As we move into this conference remember this--to a great extent the success of forestry progress in the South will depend upon the research priorities and directions decided upon now. Recent data on southern forests predicted supply and demand situation, coupled with analyses of economic opportunities, should stimulate a strong sense of urgency in all of those engaged in research and development.

We need to refine much of the data obtained by early silviculturists not because of any lack of ability on their part, but because of the more intensive forestry being practiced in the South. For example, more complete utilization results in less nutrients being left on the land, and site productivity may be adversely affected by these and other current management techniques. Harvesting, site preparation, and competition control methods are certainly much different than past practices, and probably are adversely impacting the sites. If so, how do we ameliorate.

Modeling growth and yield data for the southern pines is an active research area and will receive more attention. Such work must be extended to include genetically improved, intensively cultured stands. And we will need to determine species performance on drastically disturbed sites such as those resulting from coal mining operations.

We need to develop both even-aged and uneven-aged timber management strategies with emphasis on mixed pine-hardwood types to meet the needs of the small, private owners.

While pine will continue to receive considerable research attention, we cannot meet the South's overall land management and production goals without significant advancements in hardwood silviculture. This opens up entirely new vistas for maintaining and improving bottomland hardwood stands that are shrinking each year due to agricultural encroachments and for utilizing low-grade hardwoods on sites where pine would be more productive. Rehabilitation of degraded upland and mountain forests will be necessary to meet demands for large, high-value hardwoods now in short supply.

Some obstacles to progress in silvicultural research described by Philip Wakeley are likely to continue, but there have been tremendous changes and improvements. With all of the needs of our society we will not have all of the resources we could use to work on important problems in a timely fashion. That's why it is so important that we choose priorities carefully, coordinate what we are doing and take full advantage of opportunities to cooperate.

In summary, southern silvicultural research is alive and well. The need is real and the future is bright. The program for this conference is very ambitious and very impressive. You have a lot to share with each other and thousands of others who are not here. You have a personal responsibility to use the information that will be included in the Proceedings. Your job is not done until this information is put into practical use. And as Phil said it's "clean fun besides."

PLANTATION SURVIVAL STUDIES OF CONTINENTAL FOREST INDUSTRIES[1]

G. Kenneth Xydias[2]

Abstract.--A variety of studies were installed to identify reasons for poor survival and stocking noted in young plantation. These studies failed to show any consistent relationship between survival and the factors of type of lifting, seedling care between lifting and planting, seedling grade, or planting care. However, each of them affected survival in one or more locations. These studies suggest that all phases of a planting program must be emphasized for that program to be successful.

INTRODUCTION

The regeneration program of most pulp and paper companies in the South is characterized by intensive site preparation with mechanical equipment, followed by either hand or machine planting of genetically improved seedlings. This is an expensive system, but it is thought to provide for a greater probability of establishing a new stand and one with narrower stocking variation, than what might be expected if reliance were placed on natural regeneration.

Failure of the system to perform according to expectations may occur as a consequence of unavoidable factors such as an extended drought before the seedlings become established or because of a variety of preventable factors. These include low seedling vigor perhaps due to disease or lifting damage in the nursery, improper handling in the field, inadequate site preparation, or improper planting. There is little that can be done if weather is the major reason for poor survival, but man-caused problems are preventable, and must be identified and corrected.

Continental Forest Industries, a subsidiary of The Continental Group, Inc., and formerly known as Continental Can Company, controls approximately 1.5 million acres of forest land in the piedmont and coastal plain of seven Southern states. This land base is divided into four woodlands districts, each of which provides raw material protection for a pulp mill. These four districts site prepare and plant a total of approximately 34,000 acres of land each year. Most of this acreage is planted with loblolly pine (Pinus tadea L.), although a few thousand acres in north Florida and south Georgia are planted with slash pine (Pinus elliottii engelm. var. elliottii).

Seedlings for the reforestation effort are obtained entirely from company nurseries. One large nursery is situated near Statesboro, Georgia, and provides the seedling requirements for both the Augusta and Savannah districts. Two smaller nurseries, one situated near Chester, Virginia, and the other near Hodge, Louisiana, provide seedlings for the Hopewell and Hodge districts respectively.

Evidence that the regeneration program was not completely successful was obtained from the 1977 inventory of company land. An examination of permanent inventory plots situated in plantations younger than thirteen years old revealed a consistent and similar trend in all four districts. Stocking and survival was generally constant for plantations established prior to the early 1970's, and then began to decline for the more recently established plantations. The long-term consequences of this trend are uncertain,

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Appreciation is expressed to the numerous field personnel who were responsible for the installation and measurement of these studies, and to Messrs. M. A. Steigerwalt and R. E. Tucker for suggestions and advice in the design phases.

but the important points are that the lowered stocking level reduces management alternatives, and implies that the job is not being correctly performed.

METHODS

A two pronged approach was initiated during the 1978-79 planting season in an attempt to identify factors contributing to the declining trends in stocking. The first approach was to install several different replicated studies designed to test the effect of specific treatments. Treatments considered were mechanical lifting in the nursery, tree care between lifting and planting, planting supervision and care, etc. The goal here was simply to identify problem areas for further study. The second approach involved installation of about 275 permanent plots in 'representative' areas of newly established plantations. These plots could then be used to determine why individual trees died, and to provide clues as to where poor survival was a problem. Each of these studies can be briefly described as follows:

Lifting and Time of Planting (one location for each of two nurseries)

In this study, trees were both machine lifted with a single-row lifter and hand lifted at six different times during the planting season. Hand lifting was done carefully in order to preserve as much of the root system as possible. Planting sites were selected to represent the droughty end of the soil moisture range under the assumption that if machine lifting contributed to poor survival by breaking the fine roots, the effects of this damage ought to be more pronounced on the drier sites. Outplanting of each lifting method was replicated six times in a split plot design, with lifting date forming the whole plot. Each subplot consisted of ten trees from either lifting method.

Special Handling and Planting (20 locations)

This study was designed to identify phases in the plantation establishment system that might contribute to poor survival and to provide leads for further study. The specific phases and their objectives are as follows:

Lifting - Compare hand lifting vs. machine lifting.

Transportation and storage - Compare seedlings brought directly to the site against those being used by operational planting crews.

Planting - Compare operational planting with 'special' planting or planting in such a way as to hopefully maximize survival.

These six treatments were laid out in a randomized complete block design with five replications and fifteen trees per plot.

An additional set of treatment plots were installed to compare survival between the operational planting in the study plots and the operational planting of the adjacent area. The distinction here is that in the former situation, the planting crew was aware that they were participating in a study, while in the latter situation they were unaware that a study was being done. Any difference between these two treatments could be attributed to the effect of field supervision. These are referred to as treatment 6 and treatment 7 plots respectively.

The planting for all locations of this study was done during the middle of the dormant season to minimize possible interactions between treatments and the degree of seedling dormancy. The planting sites were variable, but were selected to represent the conditions that might be encountered in any one district.

Grading Trial (one location for each of three nurseries)

This study was established to determine if there is a survival difference between the morphological seedling grades and ungraded trees. The ungraded treatment was included as a check against the possibility that the grading process caused some survival reduction. The study design was also a randomized complete block with five replications of a fifteen tree plot. Each installation was established on 'adverse' sites under the assumption that if seedling grades were determinants of survival, their effect would be more pronounced on these sites. Planting was done in the middle of the dormant season.

Post Mortem Study

This study was established to provide (a) detailed information about why individual trees died, and (b) a data set to test hypothesis about site or management factors associated with survival. It consisted of two series of about 70 permanent plots in each district established over a wide range of conditions. Information gathered for each plot includes dates of significant management activity, i.e., cutting, preparation, planting, etc., characterization of the site, and for the second series, a description of the conditions at planting.

Each planting spot was numbered sequentially, flagged in the field, and its condition described with respect to associated vegetation. If the planting spot contained a tree, a variety of information was collected. This included tree condition (healthy, unhealthy, or dead), reason for its condition, judgements as to its size, position after planting (vertical, horizontal, etc.) and depth of planting. The first series was initially observed in April and May, 1979 or about one to three months after planting, and then again during the dormant season following one year's growth. A second series was also installed in the 1979-80 plantings, but will not be observed until early 1981.

Data Analysis

During the 1979-80 dormant season, trees in each study were characterized as being healthy, unhealthy or dead. Unhealthy trees were those that would probably die, but could not be called dead since they had a few live needles on them. Analysis of the replicated studies was based on the number of healthy trees in each plot. A first step in the analysis was to identify aberrent plots, or those whose survival was such that its probability of occurrence was less than one percent. This was done by assuming that survival in each study was distributed as a binomial, and then determining the probability associated with the number of trees in plots suspected of being aberrent. Aberrent plots could either be deleted or retained in the analysis. The data set in which aberrent plots had been deleted can be referred to as an edited data set and is the one on which the following results are based. However, inclusion of the aberrent plots had relatively little effect.

RESULTS

The geographical distribution of the study sites and of the landholdings of Continental Forest Industries is shown in figure 1. The location of the post mortem plots are not shown specifically, but they are distributed throughout the ownership. A summary of the results from the lifting and time of planting study is presented in Table 1. Analysis of variance suggests that the differences in survival between machine-lifted or hand-lifted trees at either location studied were not significant even at the twenty percent level. There was also no interaction between type of lifting and date of planting. Survival tends to decline with planting date, but this is not significant. The last planting at the Virginia location had poorer survival than the earlier plantings.

Results of the special handling and planting study are summarized in Tables 2 and 3. Table 3 shows the survival for those treatments that had a significant difference, and for the entire study. It is assumed in Table 2, that if the observed difference between any comparison has less than a sixteen percent probability of occurrence, then this difference represents an effect of the treatment and not chance variation. The higher level of significance seemed appropriate because of the generally good survival that occurred that year.

Table 3 provides the survival for the significant treatments and for each study location. A brief summary of the results by treatment are as follows:

> Lifting There was no difference in survival between hand and machine lifted trees planted at nine Coastal Plain sites. This agrees with the lifting and time of planting study. However, the survival of machine lifted trees was about five to ten percent less than hand lifted trees in five of seven piedmont sites. This occurred with seedlings from two different nurseries and is an area that should be explored in more detail.
>
> Transportation Seedlings brought directly to the planting site had significantly better survival in five of the twenty trials. Survival differences were not large however, and ranged up to twelve percent.
>
> Operational planting vs. research planting Differences occurred in only two of the 18 trials in which this treatment was installed. (Treatment 7 vs. treatment 6). If the survival of the operational planting in the planting chance (treatment 7) is compared to that achieved by all treatments in the study (treatments 1-6) this increases to four trials or a little over twenty percent. The point to note here is that while operational crews may be more conscientious about their work when putting in a study or simply because they have been chosen to do something different, there is little evidence that the study areas were planted with any more care than the remainder of the tract.

Results of the grading trials are shown in Table 4. None of the treatment means differ significantly with the exception of the Louisiana location. There, grade 3 seedlings had poorer survival than the other grades or ungraded control (P=0.01). Since these seedlings are culls and are normally discarded, this difference is of no practical significance.

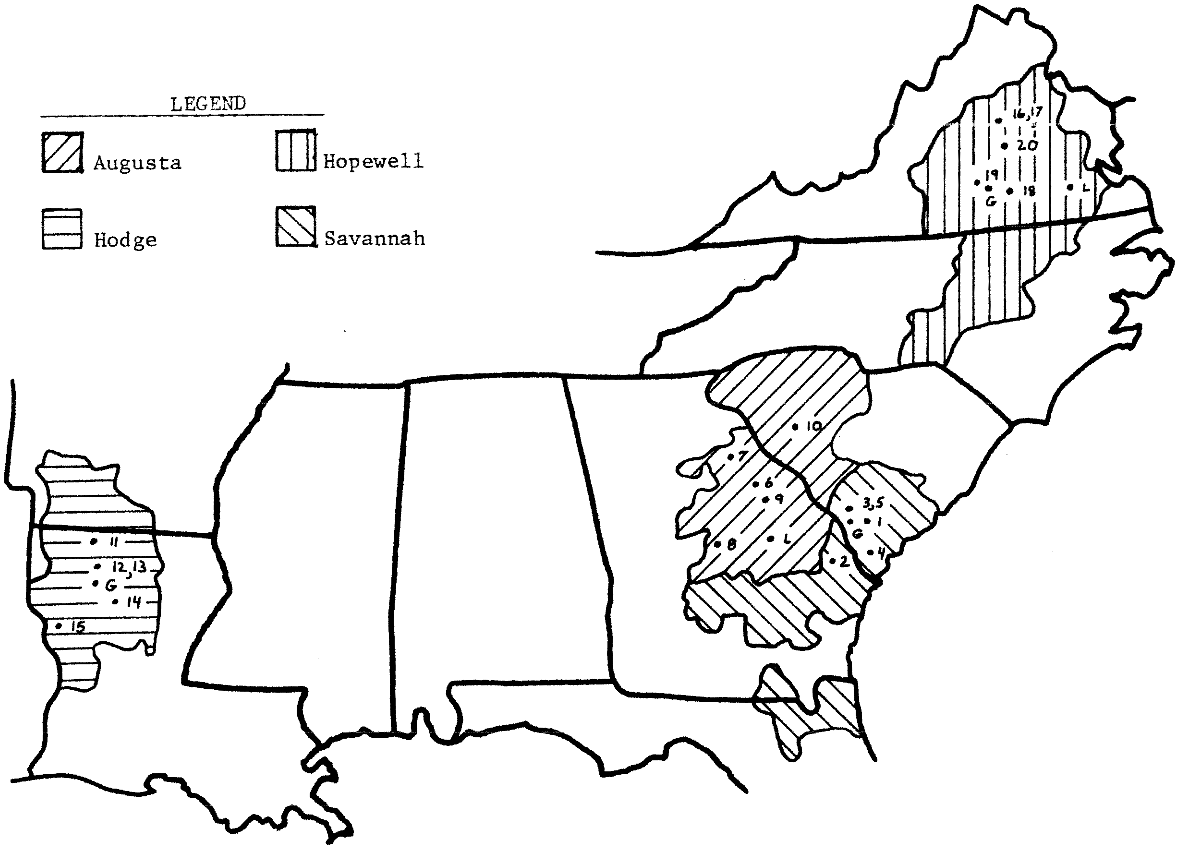

Figure 1. Land ownership and location of plantation survival studies. Study identifications are: G = grading, L = lifting and 1-20 = special handling. Post mortem plots are at various locations within shaded areas.

Table 1. Survival for Lifting And Time of Planting Study

1. Type of Lifting

	Location	
	Georgia	Virginia
Hand	97	88
Machine	95	88

2. Date of Lifting

Georgia		Virginia	
Date	Survival	Date	Survival
12/4/78	97	12/11/79	93
1/3/79	98	1/11/79	92
1/23/79	96	1/30/79	91
2/21/79	98	3/11/79	88
3/13/79	93	3/22/79	88
3/29/79	92	4/19/79	74

Although analysis of the post mortem plots is still incomplete, some results can be briefly summarized:

- The 1978-79 planting season was an excellent one for survival with a median survival ranging from 85-90 percent depending upon the district. (See Table 5). This survival from operational planting is consistent with that achieved by the special handling and other studies.
- Most mortality occurred between the time the area was planted and the plot was observed. That is, if a tree survived the planting shock, it did not die at a later date.
- Trees that did survive the planting shock but subsequently died tended to be large in size or poorly planted. Deep planting tended to confer a survival advantage, while trees that were planted shallower than normal or were slanted did not survive as well.
- There was no evidence of widespread insect, animal or disease problems. These factors were important on a few plots, but on a district or area basis, the principle reasons given for unhealthy

Table 2. PROBABILITY LEVELS ASSOCIATED WITH SIGNIFICANT TREATMENT EFFECTS.*

		SAVANNAH					AUGUSTA					HODGE					HOPEWELL				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Comparison																					
Operational Check	7 vs 6	-	-	2	-	-	-	-	-	-	-	-	-	7	-	-	-	-	X	X	-
	7 vs 1-6	-	6	1	-	-	13	-	-	-	-	3	7	1	-	-	-	-	X	X	-
Main Effects	Lift	-	-	-	-	-	12	13	-	-	7	X	X	X	X	X	3	-	-	12	-
	Transport	4	-	-	-	1	9	-	-	-	1	-	1	-	-	-	-	-	-	-	-
	Plant	-	-	-	-	-	-	13	-	-	-	-	6	-	-	-	-	-	-	-	11

* Dashed lines in any cell indicate that the probability of observed differences in treatment averages is greater than 15%.

* X's indicate that the treatment comparison was not done.

or dead trees was 'planting' or 'unknown'.

- There were more skips or missed planting spots with machine planting than with hand planting. A median value for machine planting is twelve percent in contrast to one percent for hand planting. In five percent of the cases, however, skips exceeded thirty percent for machine planting and fifteen to twenty percent for hand planting. (See Table 5)

- Planting rates vary within and between districts. The median rate was 700 trees for the Augusta district and 620 trees for the other districts (Table 5). Nominal tree spacing varied from 4-10 feet and nominal row spacing ranged from 8-13 feet.

DISCUSSION

A basic premise underlying all of these studies was that survival would exhibit an interaction between environmental factors and seedling care. That is, the only treatments that would have a high survival rate in adverse years or on adverse sites would be those in which the seedlings were treated properly. Mistreated seedlings would simply die. In good years, it was anticipated that even poorly treated seedlings would exhibit a high survival rate.

The 1978-79 planting season apparently was an excellent year as evidenced by the high median survival rates and narrow survival range shown in Table 5. This survival exceeded the 60-70 percent range that company personnel thought was typical of operational planting in prepared sites. Additional evidence of a favorable year came from the post mortem study. It revealed that trees which were so poorly planted that they were lying on the ground did not die if they were alive at the time the plot was observed.

The special handling studies clearly showed that there was no one factor that was consistently related to poor survival. Instead survival seems to be related to conditions that are unique to the site. For example, mechanical lifting seemed to be important at special handling study location number 16, the transportation system at locations 5, 10, and 12 and operational planting at location 3 and 13. This suggests that attempts to improve survival by stressing a single factor are likely to have only a modest effect. All parts of the regeneration system are equally important, and errors made in one part cannot be corrected at a subsequent step.

Many of Continental's field personnel felt that the mechanical lifter was causing considerable damage to the seedlings and adversely affecting survival. Although mechanical lifting has been shown to be detrimental to survival (Barnard 1980) there was little evidence of it here. The nursery supervisors of the two

TABLE 3. SURVIVAL BY TREATMENT AND STUDY LOCATION.

Comparison		SAVANNAH					AUGUSTA					HODGE					HOPEWELL				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Operational Planting vs Study Planting	Trt. 7	-	-	78	-	-	-	-	-	-	-	-	-	83	-	-	-	-	X	X	-
	Trt. 6	-	-	89	-	-	-	-	-	-	-	-	-	91	-	-	-	-	X	X	-
	Trt. 7	-	88	78	-	-	93	-	-	-	-	67	79	83	-	-	-	-	X	X	-
	Study	-	94	94	-	-	97	-	-	-	-	78	85	95	-	-	-	-	X	X	-
Lifting	Hand	-	-	-	-	-	99	91	-	-	95	X	X	X	X	X	97	-	-	87	-
	Machine	-	-	-	-	-	93	84	-	-	88	X	X	X	X	X	89	-	-	81	-
Transport	Direct	99	-	-	-	100	99	-	-	-	88	91	-	-	-	-	-	-	-	-	-
	Normal	95	-	-	-	95	96	-	-	-	78	-	79	-	-	-	-	-	-	-	-
Planting	Special	-	-	-	-	-	-	84	-	-	-	-	82	-	-	-	-	-	-	-	82
	Normal	-	-	-	-	-	-	90	-	-	-	-	78	-	-	-	-	-	-	-	94
Study Average		98	94	91	96	98	97	87	95	89	86	75	84	93	99	76	92	90	97	86	88

Dashes indicate that treatment comparisons were non-significant (p 0.15).
X's indicate that treatment not installed.

Table 4. SUMMARY OF THE GRADING TRIALS.

Location	Seedling Grade 1	2	3	-	Average
Virginia	94	95	89	89	92
South Carolina	65	67	67	71	67
Louisiana	93	88	72	83	84

company nurseries where machine lifting is used, however, point out that machine lifting is capable of causing a great deal of seedling damage.[1] If the machine is operated at a relatively slow forward speed and the belts are properly adjusted, then little damage will occur. However, attempts to increase production by increasing the ground speed or lifting rate will damage the seedlings. This study demonstrated that Continental's nurserymen are using the lifting equipment properly.

One use of the post mortem data is to test hypothesis about the relationships of specific practices to survival. As an example of such a test, consider the question of whether there is a survival difference between plantings done by company and contract planters. Respondents to the Southwide APA plantation survival survey expressed the opinion that survival from contract planters was inferior to that of company crews (Weaver 1980). The post mortem plots provide the data to test this opinion. It turns out that in the Hodge and Hopewell districts, the only districts that do sufficient contract and company planting to justify such a test, that there is no significant difference in average survival between company and contract crews. This is reinforced

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1/ Personal communication; J.P. Neal and T.W. Sweetland, Nursery Supervisors, Continental Forest Industries, Statesboro, Georgia and Chester, Virginia respectively.

TABLE 5. PERCENTILE DISTRIBUTIONS FOR VARIOUS PARAMETERS.

		Percentile						
Parameters	District	5	10	20	50	80	90	95
Spots (Trees/Acre)	Savannah	600	615	635	700	810	875	905
	Augusta	625	680	725	825	940	1,035	1,100
	Hodge	480	510	555	650	750	840	900
	Hopewell	450	500	550	650	740	800	875
Trees (Trees/Acre)	Savannah	495	515	540	620	720	750	800
	Augusta	500	550	600	700	875	970	1,025
	Hodge	450	500	535	620	720	820	890
	Hopewell	375	420	480	620	770	810	850
Skips (Machine) (%)	Savannah	2	3	5	13	22	28	32
	Augusta	1	3	5	11	18	21	28
	Hodge	0	1	2	6	12	16	20
	Hopewell	0	0	0	2	8	12	15
Skips (Hand) (%)	Savannah	-	-	-	-	-	-	-
	Augusta	-	-	-	-	-	-	-
	Hodge	0	0	0	0	3	6	7
	Hopewell	0	0	0	2	10	16	20
Survival (%)	Savannah	66	76	82	91	96	98	99
	Augusta	72	80	88	94	97	98	99
	Hodge	78	84	88	94	97	98	99
	Hopewell	46	54	70	85	95	97	98

by the special handling study which suggests that there was generally no difference in survival between the closely supervised study plots and the operational plantings. In addition, there is little difference in the survival distributions between the Savannah and Augusta districts even though the former district was planted almost entirely by contract crews and the latter district by company crews. The point here is that there are good and poor planting crews, and this is largely independent of whether they are company or contract crews.

The post mortem study also showed a fallacy in attempts to determine survival with any degree of accuracy one or more years after planting. Survival by definition is the number of live trees expressed as a percentage of the number planted. The number planted cannot be estimated by assuming that planting is being done at some constant rate or that gaps observed in a row of trees one or more years after planting represent dead trees. Although skips only averaged about twelve percent for machine planting and was much lower for hand planting, they could range as high as 20-30 percent (Table 5). Accurate estimates of survival require that the number of trees planted is known. This can only be done by a post planting cruise to determine planting rates or by the establishment of permanent plots in each planting chance on which both planting and mortality rates can be determined.

One possibility for the declining trends in stocking which Continental noted on their permanent inventory plots is simply that we have been tending to plant fewer trees/acre. This is consistent with our response and probably that of forest industry as well, to the deteriorating economic conditions of the 1970's. That is, attempts were made to reduce costs in all areas of the regeneration program. This included such things as reducing site preparation inputs, consolidation of site preparation activity with attempts to prepare sites when administratively convenient, and elimination of hand planting crews to correct skips and poor planting of machine planted trees. In addition, the sites being prepared during this period generally tended to be the more difficult sites.

The question that remains unanswered is the extent to which the favorable weather masked handling and other problems. Would the slight survival differential observed in a few of the replicated studies be repeated in an adverse year but with overall survival at a much lower level, or would this survival differential be enlarged with only the properly handled seedlings having a good survival? This question cannot be answered until the replicated studies are repeated in an adverse year. In the meantime, a prudent course of action is to simply recognize the fact that all facets of the regeneration system are equally important, and that stressing a single facet is likely to do little to improve the overall survival picture.

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LONGLEAF PINE SEEDLING SURVIVAL STUDIES[1/]

by J. Andrew Parker and L. Wayne Haines[2/]

Abstract.--Effects of needle clipping, clay root dips, and refrigerated storage on survival of longleaf pine (Pinus palustris Mill.) seedlings from four nurseries were studied in southwest Georgia. First-year survival of unclipped seedlings ranged from 4% to 85%, although seedlings were similar in external characteristics. Average survival was 88% for clipped seedlings from the two best nurseries. Overall, needle clipping increased survival 12 percentage points and clay root dips reduced mortality from exposure. Sixty-five percent of clay-dipped seedlings survived 80 minutes of drying in full sunlight. Seventy-four percent of seedlings survived when outplanted after 31 days of refrigerated storage in sealed bags.

INTRODUCTION

The Great Southern Lumber Company planted longleaf pine during the 1920's (Spencer 1979, Wakeley 1969). The species has been planted on a limited scale throughout the South since then, but planting failures have been common. Shoulders and Walker (1979) reviewed the results of 113 planting trials of four pine species planted between 1954 and 1958 in Louisiana and Mississippi. First-year survival results were reported as follows: loblolly (P. taeda) 77%, slash (P. elliottii) 69%, shortleaf (P. echinata) 78%, and longleaf 54%. Landowners often plant loblolly or slash rather than longleaf because they believe the latter is more difficult to regenerate (Mann 1969).

The North Carolina Forest Resources Division and T. R. Miller Company have recently shown that longleaf can be successfully planted operationally (Goodwin 1978, Moody 1978). During the past several years International Paper Company has successfully established longleaf plantations in south Alabama, but elsewhere failures have outnumbered successes. International Paper expanded its longleaf pine research efforts in 1978 with the objective of learning how to fully utilize the species in its intensive forest management program. This paper reports early efforts to improve survival of 1-0 seedlings planted at Southlands Experiment Forest (SEF) near Bainbridge in southwest Georgia.

METHODS

Seedlings from four nurseries (coded A, B, C, and D) were lifted, packaged, and transported to SEF under the supervision of the senior author. Seedlings were graded, dipped, clipped and repackaged at SEF in an enclosed shed. All studies were conducted with seedlings carefully graded to root-collar diameter ≥ 12 mm and dibble-bar planted.

Plantings were established in February 1979 on disked sites and soil moisture was favorable for tree development. Predominant soil series of the study sites were Lakeland, Eustis, and Wagram. Plots were 100 m^2 and contained 50 marked seedlings. Survival was determined during the fall of 1979 and an analysis of variance was used to evaluate individual studies. Treatment differences were determined by Tukey's test at the 95% level.

Treatments tested in separate studies were: (1) needle clipping, (2) refrigerated storage, and (3) clay dipping and root exposure. Needle clipping consisted of cutting needles to a length of 13 cm just prior to planting. Seedlings were stored at 1°C for 1, 10, 17, and 31 days in sealed kraft paper seedling bags. Moist peat moss was used as a packing medium and the bags were inspected for holes before storage. Seedlings with

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[2/] J. Andrew Parker is Project Leader, Dry Site Research and L. Wayne Haines is Senior Research Forester, Southlands Experiment Forest, International Paper Company, Bainbridge, Georgia.

roots dipped in a thick kaolin clay slurry were compared with non-dipped seedlings for periods of 0, 20, 40, and 80 minutes in full sunlight. Air temperature was 12°C and wind velocity estimated at 7 km per hour during the exposure period. All treatments were replicated either five or six times in complete randomized blocks.

RESULTS AND DISCUSSION

Survival Comparisons

Seedlings in control plots were used to compare survival by nursery source. These were unclipped and undipped seedlings that had not been unnecessarily exposed to sunlight. Survival ranged from 4 to 85% by nursery source (fig. 1). This wide range was completely unexpected because of the care given the seedlings from time of lifting to outplanting. Futhermore, all seedlings were planted by the same crew within seven days after lifting.

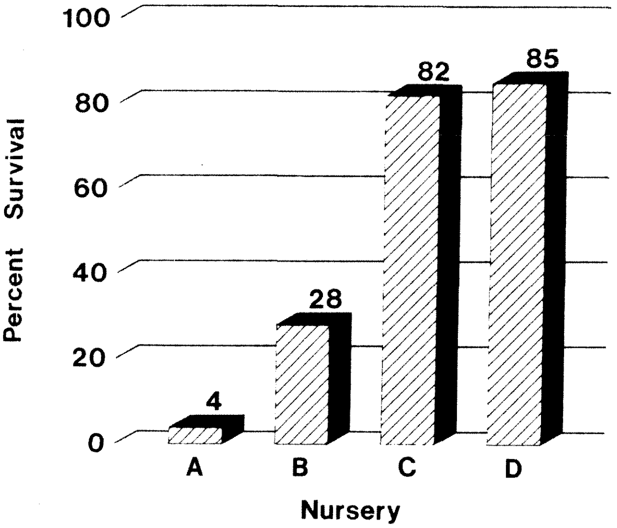


Figure 1.--First-year survival of untreated and unclipped longleaf pine seedlings from four nurseries.

Survival checks of operational plantings using the same nursery sources revealed obvious survival differences and support observations on the research plots. Plantings with seedlings from nursery A failed while plantings from C and D were successful.

The survival differential could have resulted from nursery management, seed source, or both. Nursery visits during the growing season revealed obvious differences in needle length, methods of weed control, and seedlings/m³. Later, when the seedlings were graded, the percentage of undersized plants varied by nursery. Brown-spot disease was not recognized as a problem with any source. Physiological quality of seedlings probably varied by nursery. Wakeley (1954) discussed seedling quality and physiological quality and observed that morphological grades and physiological quality do not necessarily coincide. Thus, even when only grade 1 seedlings are planted, nursery management can impact survival.

Provenance studies have shown longleaf survival and growth varies with seed source (Snyder, et al. 1977). The four nurseries are located in Alabama, Georgia, Louisiana, and South Carolina. Some are state operated and others are private. Some nurseries obtained local seed while others purchased their seed and the source was unknown. Thus, seed source was a factor that cannot be separated from nursery management differences in this study.

Foresters should be aware that longleaf survival can vary greatly by nursery and should record nursery source on their planting records. Nurseries growing seedlings that fail to survive should be informed of the problem. Futhermore, foresters should avoid such nurseries when obtaining seedlings.

Needle Clipping

Effects of needle clipping on survival were studied with seedlings from nurseries A, C, and D. Clipping increased survival of all sources by an average of 12 percentage points (fig. 2). These results generally agree with those reported by Allen (1955) and Allen and Maki (1951). However, a strong treatment-nursery interaction was evident in this study. Sources C and D which survived well without clipping (79% and 78%) were improved by 8% and 10%, respectively. Survival of source A seedlings was very poor without clipping, but increased 19 percentage points with clipping. These results reinforce the idea that differences in physiological quality probably existed among nursery sources. Increased survival from clipping was attributed to reduced moisture loss from a smaller needle surface area.

Refrigerator Storage

Nursery D seedlings were used in the refrigerated storage study. Storage up to 31 days did not significantly reduce first-year survival but a downward trend was observed after 17 days (fig. 3). This study indicates that high quality dormant seedlings can be held up to three weeks in sealed bags @ 1°C with little loss of viability. Other studies have shown a drop in longleaf survival following seven days of storage in open buildings (Allen 1955, Slocum and Maki 1959, White 1978).

These results are important because regeneration operations need the option of storage to avoid problems associated with bad weather that adversely affects lifting or planting. Futhermore, knowing that longleaf seedlings can be stored successfully, foresters can address other possible causes of planting failures.

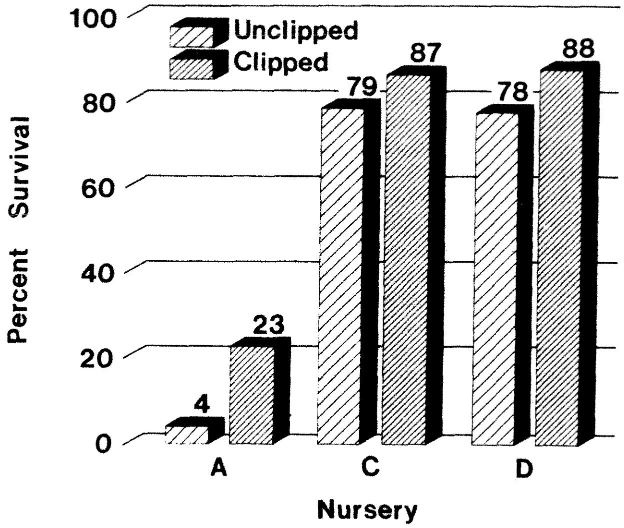


Figure 2.--Effects of needle clipping on first-year survival of longleaf pine seedlings from three nurseries.

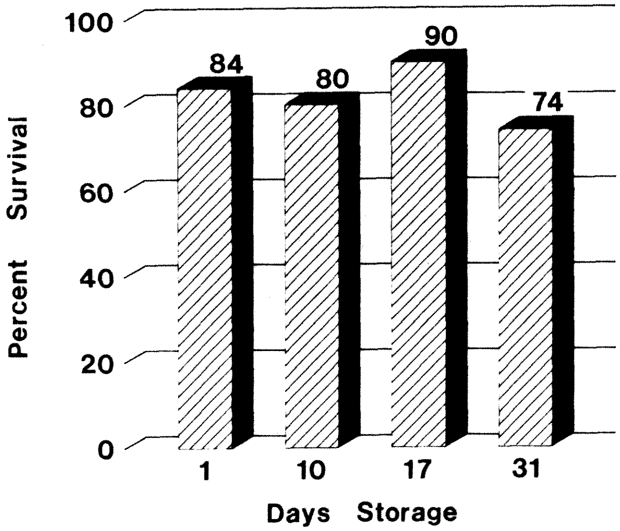
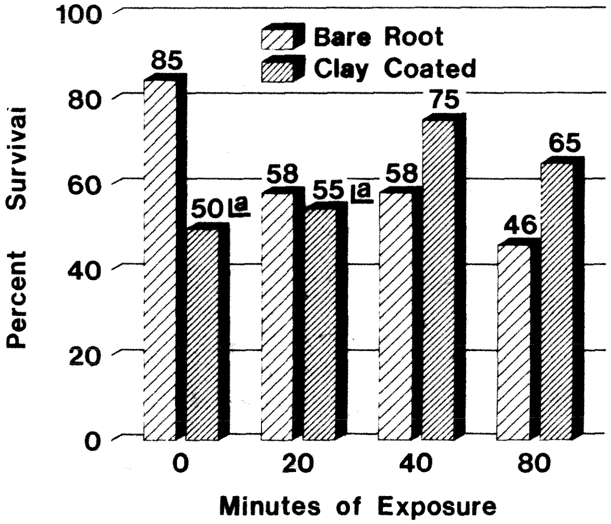


Figure 3.--First-year survival of longleaf pine seedlings after 1, 10, 17, and 31 days of refrigerated storage.

Clay Dipping

The clay root dip study was compromised when seedlings from nurseries A and C were inadvertently mixed; however, the results are reported because they show encouraging trends. Undipped seedlings from nursery C were exposed for 0, 20, 40, and 80 minutes. Clay-dipped seedlings of the same source were exposed for 40 and 80 minutes, but some source A seedlings were used for the dipped 0 and 20 minute comparisons. Thus, the comparisons for exposure periods of 40 and 80 minutes, that show survival increases of 17 and 19 percentage points are valid (fig. 4). The dipped and undipped comparisons shown for 0 and 20 minutes of exposure are invalid because of seedling source differences.



a/ Survival was lower than expected due to a nursery source mistake.

Figure 4.--First-year survival of longleaf pine seedlings with bare and clay-coated roots after 0, 20, 40, and 80 minutes of exposure.

This information and other research shows that longleaf pine seedling survival can be enhanced by clay dipping their roots (Slocum and Maki 1959, Wakeley 1954). This practice should be used where exposure of seedling roots is anticipated.

SUMMARY

Longleaf survival can vary greatly among nursery sources even when only grade 1 seedlings are planted. In this study the differences among nursery sources may have been due, at least in part, to seed source differences. Thus, additional research is needed to learn more about the effects of nursery management on seedling survival.

Needle clipping enhanced survival, but the degree of improvement varied with nursery source. Clipping had the greatest impact on the source that otherwise had very poor survival. Seedling survival with exposure was improved by dipping roots in a clay-slurry. This treatment should be used where planting activities are likely to result in roots being subjected to drying conditions.

Longleaf seedlings store well when sealed in paper bags at 1°C temperature for as long as three weeks. Proper storage combined with needle clipping and root dipping, when necessary, should enhance survival potential of seedlings except when nursery management results in poor physiological quality.

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THE EFFECT OF WRENCHING AND PLANTING DATE
ON THE SURVIVAL OF LOBLOLLY SEEDLINGS[1]

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and
John G. Mexal[2]

Abstract.--Outplanted undercut nonwrenched loblolly seedlings survived as well as seedlings wrenched every 21, 33, or 45 days. In a replicated planting, survival was roughly equal for seedlings planted in central Louisiana and southwestern Arkansas for the dates November 15 and January 15. However, survival of the March 15 planting was less in Louisiana. Wrenching did not alter seedling morphology nor did it increase lateral root development.

Root wrenching of *Pinus radiata* seedlings has been a common nursery treatment for more than 50 years in New Zealand (Goudie 1935). Wrenching, in combination with undercutting and lateral root pruning, improves survival of early lifted and planted seedlings. The increased survival of seedlings lifted in early winter is an important aspect because large planting programs depend upon lifting and planting prior to the onset of winter (van Dorsser and Rook 1971).

Wrenching is preceded by undercutting of seedlings. This cuts the tap root and initiates new lateral roots. About 4 weeks after undercutting, the first wrenching is done by pulling a tilted (20° from horizontal) spring steel blade under the seedling bed. The blade operates off a lobed cam which is designed to cut a 10 cm sideways stroke. During the sideways stroke the tilted blade travels forward about 4 cm. The reciprocating action permits the blade to pass under the seedlings without pulling them down into the beds (van Dorsser and Rook 1971).

The popularity of root wrenched nursery seedlings is also related to the change in seedling morphology. Undercutting and wrenching inhibit height growth, but root growth is relatively unaffected on a dry weight basis (Benson and Shepherd 1977). Thus, wrenched seedlings have a higher root-shoot dry weight ratio. Wrenched seedlings also tend to have a more fibrous root system and better mycorrhizal development than nonwrenched seedlings. Other morphological changes resulting from wrenching are a smaller shoot, more secondary needles, and greater needle cast on the lower stem (Rook 1971).

Wrenching operations should begin when seedlings reach the desired height for field planting. The initial wrenching is done at a below-ground depth which will stop height growth and at a time when climatic conditions are favorable for seedling growth. If the seedlings are undercut too early, they will not reach a plantable size and if they are undercut too late, they will not respond to root wrenching because they will have passed the optimum season for photosynthesis. Another important aspect of wrenching is to develop a regime that will maintain the desired shoot/root morphology. A monthly wrenching regime is best for *P. radiata* seedlings.

An optimum nursery root pruning regime has not been developed for loblolly pine, although recent tests have indicated that this species may also benefit from wrenching (Tanaka et al. 1976). This report describes results of a test designed to compare the effect of different wrenching regimes on morphological characteristics of loblolly pine nursery seedlings and the survival of seedlings lifted in early, mid- or late-winter.

MATERIALS AND METHODS

A 240-meter section of a typical loblolly nursery bed at the Weyerhaeuser Corporation forest nursery in Magnolia, Ark., was selected for this study. Bed density was approximately 290 seedlings per square meter. The entire bed was undercut at approximately 18 cm on August 13, 1979, when the seedlings were approximately 20 cm tall. This was

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considered to be a baseline treatment and from this date the following wrenching treatments were done for randomly assigned 15 m plots. Each of the four treatments was replicated four times within the 240 meter bed. The treatments were: a) control seedlings that were undercut once, but not wrenched; b) seedlings wrenched every 21 days; c) seedlings wrenched every 33 days and d) seedlings wrenched every 45 days. The individual plots were separated by a 0.3 m strip where the seedlings had been removed. This cleared strip was used as an area to insert or remove the wrenching blade.

Prior to the first wrenching on August 13, 10 seedlings were pulled from each of 15 randomly selected sample points in the center section of the nursery bed. Their mean root collar diameter was 2.8 mm and their mean height was 19.9 cm. Edge row seedlings were not included in this sample in order to obtain an unbiased estimate of the average seedling in the nursery bed.

Wrenching intervals were adhered to, except when a scheduled wrenching fell on Sunday. In this case the seedlings were wrenched on the following Monday. The wrenching blade was set to operate at 12 cm below soil surface. This depth was maintained throughout all wrenchings and periodic checks during wrenching indicated blade depth was close to 12 cm. The seedlings were lateral root pruned in mid-August and early October.

Immediately following each wrenching the seedlings including the controls were watered to avoid tip wilt and possible dieback of the succulent, tender tips which frequently occur following extensive loss of the root system as a result of root wrenching. Because of an unexpected outbreak of *Phomopsis* mainly on the tallest seedlings, the entire seedling bed was top pruned to 25 cm in early September. Only a few seedlings were actually top pruned since most were smaller than 25 cm. Root collar diameter, height and dry weight measurements were taken from a 0.3 meter section across the individual plots prior to undercutting on August 13 and at each lifting date. Every seedling lifted in this sample was measured. The seedlings were hand lifted by undercutting again to sever new tap root growth. After lifting, seedlings were wrapped in canvas, taken to nursery tables, and graded to remove small, diseased, broken and malformed seedlings. Only seedlings with a 3 mm or greater root collar diameter were retained. All of the seedlings had secondary needles. After grading they were placed in kraft-polyethylene bags and their roots sprayed with a kaolin clay slurry. All seedlings were stored at 2° C until outplanted.

Seedlings were lifted on November 15, January 15, and March 15 and outplanted the following day in central Louisiana and southwestern Arkansas. Two groups of 50 seedlings were lifted from each nursery treatment plot and were outplanted for each of these planting dates on each planting site. On the day of planting the seedlings were removed from the K-P bags and wrapped within a moist burlap bag and placed in standard planting trays or bags. They were hand planted at a 0.6 x 1.2 meter spacing. The central Louisiana site located on the Johnson Tract of the Palustris Experimental Forest was bush hogged, burned and disked prior to planting. The soil is a sandy loam and the planting site is flat, but well drained. The Arkansas site, near Murfreesboro, had been recently clearcut, chopped and burned. The soil is a clay loam and the slope is less than 5 percent.

RESULTS

Initial Seedling Condition

After wrenching there was no visual evidence that seedlings suffered serious shock nor was any mortality observed. The seedlings continued to grow, both in height and root collar diameter. There are several references that show wrenching suppresses shoot growth, but all indications in this study show that root growth is not affected adversely. If affected, root growth in this study appears relatively greater, because of the stimulatory effects of pruning on propagation for new roots from the severed tips (Benson and Shepherd 1977; Tanaka et al. 1976).

Treatment Effects on Seedling Morphology

Average height of seedlings before undercutting was 19.9 cm. Seedling height measurements taken on November 15 were as follows: 21.0 cm for the controls; 20.7 cm for the 21 day wrenching regime; 21.0 cm for the 33 day wrenching regime; and 20.8 cm for the 45 day wrenching regime (table 1). These height means were not statistically significant at the 5 percent level. The effect of wrenching on seedling root collar diameter and total number of secondary roots also failed to show any significant differences (table 1). The mean root collar diameter of the control seedlings was 3.7 mm. Mean root collar diameters of the wrenched treatments were 3.7 mm, 3.6 mm, and 3.3 mm, for the treatments 21, 33, and 45 days respectively. These differences were not statistically significant at the 5 percent level. The mean number of secondary roots ranged from 8.9 to 10.1 per seedling. These differences also were not significant statistically.

Field Performance

Seedlings lifted on January 15, 1980, were uniform in morphological characteristics (table 1). Mean root collar diameters ranged from 3.5 to 3.6 mm for the four treatments. Mean seedling heights ranged from 18.9 cm to 20.2 cm, and the number of lateral roots ranged from 8.9 to 9.6 per seedling at treatment. There were no significant differences among the measurements for any of the data in this table.

Table 1.--Mean height, root collar diameter, and number of lateral roots for seedlings wrenched every 21, 33, or 45 days and control seedlings. The first figure is for seedlings lifted on November 15, 1979. The second and third figures are for seedlings lifted on January 15 and March 15, 1980. Means are followed by their standard error.

Wrenching treatment	Height	Root collar diameter	Number of lateral roots
	cm	mm	
Control	21.0 ± 0.54 20.2 ± 0.92 20.4 ± 1.10	3.7 ± 0.05 3.6 ± 0.05 3.8 ± 0.32	8.9 ± 0.13 8.9 ± 0.62 9.4 ± 0.39
21 days	20.7 ± 1.06 18.9 ± 0.36 19.9 ± 1.08	3.7 ± 0.00 3.6 ± 0.09 3.7 ± 0.23	9.5 ± 0.50 9.6 ± 0.16 11.1 ± 0.57
33 days	21.0 ± 1.12 19.8 ± 1.37 20.6 ± 1.52	3.6 ± 0.10 3.6 ± 0.16 3.8 ± 0.14	9.8 ± 0.51 9.3 ± 0.20 9.7 ± 0.39
45 days	20.8 ± 0.48 19.2 ± 0.78 21.5 ± 0.78	3.3 ± 0.11 3.5 ± 0.15 3.9 ± 0.06	10.1 ± 0.27 9.6 ± 0.55 10.1 ± 0.72

Seedlings lifted on March 15 followed the same trend with no real difference between treatments (table 1). The root collar diameters of the seedlings averaged 3.8 mm. Mean seedling heights were 20.4 for the control and 19.9, 20.6, and 21.5 cm for 21-, 33-, and 45-day wrenching treatments, respectively. Mean number of secondary lateral roots ranged from 9.4 to 11.1 for the four treatments.

Although the data are not statistically significant there was a slight increase in root collar diameters between November and March. This is probably a normal growth response and not related to wrenching. Height growth did not occur and there was no detectable increase in number of secondary roots between November and March.

By early summer, weather patterns indicated a record heat and drought period. Consequently, we decided to make a preliminary survey in July to assess differences in survival in case the drought continued. The first survey was made on July 1 for the Arkansas planting and July 14 for the central Louisiana planting. The heat wave combined with the dry weather continued until October and for central Louisiana it was considered to be the driest and hottest summer in 50 years. Consequently, seedlings in this study were put to a severe test of survival capability.

Survival for the seedlings planted in southwestern Arkansas was date dependent. On July 1, 1980, 79.5 percent of the seedlings planted on November 15, 1979, were alive (table 2). Seedling survival averaged 95.8 percent for the seedlings planted on January 15 and 95.5 percent for the seedlings planted on March 15. A two-way ANOVA test revealed no statistical differences (5 percent level) in survival due to treatments or planting date for these later plantings. Survival percentages for this date and for all following dates were transformed to their corresponding arc-sin values for analysis.

Table 2.—Percent survival of wrenched seedlings planted in early, mid-, and late-winter. The seedling survival counts were made on July 1, 1980. The upper figure refers to the planting at Murfreesboro, Arkansas, and the lower figure refers to the planting in central Louisiana. Each mean represents the percent of 400 seedlings originally planted. Means are followed by their standard error.

Wrenching frequency	Planting date Nov. 15, 1979	 January 15, 1980	 March 15, 1980	 $\bar{x}$
		% Survival		
Control	76.5 ± 2.77 99.3 ± 0.53	94.2 ± 2.02 99.8 ± 0.33	94.6 ± 1.61 99.7 ± 0.50	88.4 99.6
21 days	81.5 ± 4.24 99.5 ± 0.50	97.2 ± 0.84 100.0 ± 0.00	93.2 ± 2.70 99.0 ± 0.65	90.6 99.5
33 days	78.8 ± 5.07 99.5 ± 0.50	95.2 ± 1.51 100.0 ± 0.00	97.2 ± 1.31 99.5 ± 0.50	90.4 99.7
45 days	81.2 ± 2.42 98.8 ± 0.65	96.5 ± 1.05 100.0 ± 0.00	97.0 ± 1.46 99.0 ± 0.76	91.6 97.2
$\bar{x}$	79.5 99.3	95.8 99.9	95.5 99.3	

In central Louisiana seedling survival was uniform among wrenching treatments and planting dates (table 2). Survival was 99 percent for the control and wrenched seedlings. The lower survival for seedlings lifted and planted in mid-November in Arkansas illustrates that lifting date may be more important for survival in the northern range of loblolly than in the southern range.

A second survival measurement was made in the last week of September and the results reflect the drastic impact the long drought had on survival. At the Murfreesboro planting site, survival dropped from a mean of 79.5 percent for the November 15 planting date to 55.5 percent by late September. The seedlings planted on January 15 dropped from 95.8 to 67.7 percent survival, while survival of the seedlings planted on March 15 fell from 95.5 to 60.1 percent. These survival means between planting dates although ranging from 55.5 to 67.7 percent were not statistically significant at the 5-percent level (table 3). The mean survival between the four wrenching treatments ranged from 59.5 to 62.5 percent and likewise these differences were not statistically significant at the 5-percent level.

Statistical analysis of the seedlings planted in central Louisiana also revealed that by late September overall survival was significantly lower. Mean survival between seedling treatments ranged from 54.3 to 59.7 percent but differences among means were not statistically significant at the 5-percent level. However, a two-way analysis of the data revealed statistical differences among the means ($p < 0.01$) for planting date. Comparison of the planting date means by using the Student Newman-Keuls test indicated that seedlings planted on March 15 were statistically different from those planted on the other dates. Overall survival was 43.9 percent for this planting date versus 64.8 percent for the seedlings planted on November 15 and 60.3 percent survival for those planted on January 15 (table 3).

Table 3.--Percent survival of wrenched seedlings planted in early, mid-, and late-winter. The seedling survival counts were made on September 30, 1980. The upper figure refers to the planting at Murfreesboro, Ark., and the lower figure refers to the plantings in central Louisiana. Each mean represents 400 seedlings. Means are followed by their standard error. Different letters behind means indicate statistical difference at ($p < 0.01$).

Wrenching:	Planting Date			
frequency:	Nov. 15, 1979	January 15, 1980	March 15, 1980	$\bar{x}$
	% survival			
Control	57.0 ± 5.55 67.0 ± 5.92	72.8 ± 5.88 64.5 ± 2.85	57.7 ± 7.96 47.3 ± 8.56	62.5a 59.6a
21 days	57.8 ± 7.93 64.0 ± 3.82	66.5 ± 6.06 60.8 ± 4.16	57.3 ± 6.24 44.6 ± 4.26	60.5a 56.5a
33 days	53.5 ± 8.35 62.0 ± 3.61	71.5 ± 4.73 57.6 ± 2.80	60.5 ± 6.37 44.6 ± 3.66	61.8a 54.7a
45 days	53.5 ± 5.93 65.6 ± 5.37	60.0 ± 4.20 58.2 ± 3.01	65.0 ± 8.94 39.2 ± 4.95	59.5a 54.3a
$\bar{x}$	55.5a 64.8a	67.7a 60.3a	60.1a 43.9b	

DISCUSSION

Wrenching did not stimulate lateral root development of loblolly pine to the extent reported for *P. radiata* seedlings. Actual counts of roots for each treatment showed that wrenching did not significantly increase the mean number of lateral roots. Part of the root response to wrenching could be lost in the lifting operation. Although particular care was taken in lifting seedlings, some fine lateral roots were unavoidably lost. The loss of fine lateral roots is unavoidable particularly in mechanical lifting operations. Thus, until a method is found to save these lateral roots, wrenching may not result in seedlings with more actual roots after lifting from the nursery beds.

A potential problem of wrenching or undercutting is root deformation. The tap roots were pulled or oriented in the direction of the blade cut and consequently formed an L-root configuration. We do not have any quantitative data on the incidence of this root deformation or of its effect on performance.

It appears that loblolly as a species has poorer root development than *P. radiata* which has been extensively studied for its response to wrenching. Root regeneration of loblolly seedlings may be significantly different from that of other species. It is also possible that the wrenching plus lateral pruning methods in this study were not sufficiently drastic enough to stress the seedlings.

Some seedling roots grow down the seedling row and avoid pruning. Thus, the seedlings may channelize a larger part of their energy into these unpruned roots. We suspect that most of these long, but small diameter secondary lateral roots are lost when the seedlings are lifted.

Energy for new root growth may preferentially sink into wound healing of severed roots and into existing undamaged (unpruned) roots rather than in the formation of new laterals off pruned lateral roots. Also, it appears that lateral root development is harder to induce along the primary root as this root ages or undergoes differentiation. The optimum zone for new root development probably moves down the tap root and outwards on each lateral root as they grow longer. Repeated severing at 12 cm does not result in a massive development of new tap roots just above the cut root.

Wrenching was not as crucial for seedling survival as was planting date. We are not sure why wrenched seedlings failed to perform better than the nonwrenched seedlings. It may be that the root systems were not stimulated to branch. For whatever the reason, this study did not show any advantage for wrenched seedlings. However, given the results obtained with *P. radiata* we feel that additional tests should be carried out on southern pines to fully explore the potential of wrenching.

The lack of any significant morphological and survival differences between the wrenched and control seedlings may be a result of the single undercutting that the seedlings received on August 13, which was the baseline point for the study. This undercutting may have been sufficient to shock the seedlings and to shut down their growth.

Tanaka et al. (1976) reported that loblolly seedlings, in an earlier wrenching study at the Magnolia Nursery, had many of the characteristics reported for *P. radiata* seedlings. In particular, they were able to detect lower shoot:root ratios, smaller shoot systems and smaller root collar diameters. Survival was also better for wrenched seedlings when planted on a droughty site. Root dry weight was not different from the controls although there were proportionately more lateral roots on the wrenched seedlings than on the control nonwrenched seedlings.

Walstad et al. (1977) reported that wrenched loblolly seedlings had slightly smaller root collar diameters, a slight decrease in shoot length, and moderate increase in the proportion of lateral roots. These changes were suggested in this study, but we were unable to show they had occurred statistically.

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ECTOMYCORRHIZAL CONDITION OF PLANTED PINES: WHAT DIFFERENCE DOES IT MAKE?[1]

John L. Ruehle[2]

Abstract.--Failure of nurserymen and reforestation specialists to acknowledge the biological importance of ectomycorrhizal development on seedling stock increases the chances for reforestation failures. Although the need for high-quality seedlings is widely recognized, quality often is rated only on aboveground portions. Roots are often mistreated and ignored. Roots are usually monitored only at lifting time, after all factors contributing to their development have occurred. Condition and quality of the seedling root system at planting is of prime importance in survival and early growth. Since ectomycorrhizae increase root surface area, improve uptake of water and nutrients, maintain resistance to adverse soil conditions and provide some protection from damage by feeder root pathogens, ectomycorrhizal development on pine planting stock is a determinant of seedling quality. Factors that influence root system development are also likely to affect ectomycorrhizal development. All procedures from lifting to planting should be designed to retain the majority of the lateral roots and attached ectomycorrhizae.

INTRODUCTION

Although most nurserymen and reforestation specialists producing and planting pines would agree with Zobel (1979) that seedling quality is important, they often fail to agree on a common definition of quality. Nurserymen usually rate quality of seedlings on above-ground portions and too often ignore the roots during the production period. Why? Possibly because in the nursery roots of seedlings are not visible and their development is difficult to monitor. After the seedlings are lifted, some consider top:root ratio, height, fresh weight per 1000 seedlings, and presence of secondary needles and buds as measures of quality; others consider nonvisible internal differences, such as starch levels, percent vascular tissue, and percent moisture, the qualities to rate. All of these factors working in concert undoubtedly influence the capacity of seedlings to survive and grow well after planting. Nurserymen would probably agree that the condition, both physiological and morphological, of the root system of pine seedlings is important, but it would be difficult to obtain a consensus on an optimum root grade (woody and fibrous roots) for survival and rapid early growth of planted pines.

Reforestation specialists also have a general concern for seedling quality. They know that high quality seedlings planted without root deformity on properly prepared sites usually survive and grow well. They often warn planting crews to guard the root systems from drying or exposure to freezing temperatures. However, their main concern during the planting operation is usually the depth of planting and avoidance of root deformity.

Too few nurserymen and reforestation specialists have a working concept of pine root systems and the importance of ectomycorrhizae.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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Most of the feeder roots of pine seedlings growing in a natural environment have abundant ectomycorrhizae--a symbiotic association between mycorrhizal fungi and succulent short roots. This symbiotic association increases root surface area, uptake of water and nutrients, and resistance to adverse soil conditions and some feeder root pathogens.

Wakeley (1954) reported years ago that loss of lateral roots on slash and longleaf pines prior to planting markedly decreased field survival. More recently, Dierauf and Garner (1978) found that severe root pruning of loblolly pine significantly reduced field survival. If significant numbers of third- and fourth-order laterals (the roots supporting ectomycorrhizae) are lost prior to planting, seedlings must regenerate new laterals and form ectomycorrhizae before aboveground growth can start. This regeneration is dependent on the stored food in the stem and tap root. If stress occurs while the seedlings are regenerating new roots, chances for mortality increase.

Wakeley also recognized and reported back in 1954 that ectomycorrhizae are essential to good mineral nutrition of southern pines. Why then is there so little regard today for retaining ectomycorrhizae on pine seedlings prior to planting? Nursery experts tell us that better handling during seedling lifting, storage, and transport is necessary to ensure optimum field survival and early growth of planted pine seedlings. Yet too many, I find today, have little regard for retaining ectomycorrhizae on seedling root systems. Even if pine seedlings arrive at the planting site with adequate numbers of ectomycorrhizae attached to the lateral roots, I find that too many tree planters disregard, or are simply unaware of, the need to retain ectomycorrhizae on plantable seedlings. Tree planters, in an attempt to avoid root deformity during planting, often reshape the root system to accommodate the shape of the hole made by the planting tool--a procedure that causes a significant loss of ectomycorrhizae.

Nurserymen and reforestation specialists know that seedling quality and better handling improve field performance, but they often are less certain how and why these things work. Perhaps one reason the nursery practices employed to produce quality pine seedlings often succeed is that they encourage the development of suitable ectomycorrhizal root systems. Better handling methods in lifting, grading, packaging, storing, transporting, and planting have been developed through trial and error to improve survival and early growth after planting, often with little understanding of the biological mechanisms at work. When these methods are examined from a biological point of view, I believe we will find they work because they provide, among other things, for the retention of viable ectomycorrhizae on the planting stock.

The current consensus of forest scientists is that, with all other factors equal, pine seedlings with abundant ectomycorrhizae at planting survive better and grow faster than seedlings with few ectomycorrhizae. Our research results at the Institute for Mycorrhizal Research and Development have reaffirmed this hypothesis. We advocate that nurserymen devise means to protect the lateral roots with ectomycorrhizae during lifting and avoid drying and deterioration of these delicate roots during storage and transport. We further suggest that pine seedlings be planted with the most complete and intact root system possible. The complaint will come from the planting sites--"Seedlings with all these fibrous roots are too difficult to plant." Once we convince the regeneration specialists and their supervisors that the retention of fibrous roots and attached ectomycorrhizae will improve survival and early growth, they will develop the technology to overcome this difficulty.

Since the objective of reforestation with pines is maximum survival and rapid growth of newly planted seedlings and since we know that abundant ectomycorrhizae are essential to this goal, let us consider means of lifting, grading, storing, transporting, and planting pine seedlings that will retain the maximum complement of functional ectomycorrhizae.

BARE-ROOT SEEDLINGS

Southern nurseries rarely have problems producing 1-0 pines with abundant ectomycorrhizae --abundant meaning that over half of all short roots are ectomycorrhizal. Fumigation of nursery soil results in a reduction of both pathogenic and symbiotic fungi. Airborne basidiospores released from naturally occurring ectomycorrhizal fungi in forests adjacent to nurseries usually reinfest the fumigated soil by mid June. Barring any detrimental cultural procedures, i.e., misuse of pesticides, excessive N or P fertilizer applications, or root disease harmful to root development, the pine seedlings will develop abundant ectomycorrhizae by the end of the growing season.

Root undercutting, wrenching, and lateral pruning induce a more fibrous and compact root system on pine seedlings. In addition to creating seedlings physically adapted to today's planting techniques, these practices alter root configuration and create the framework for supporting an increased number of second- and third-order laterals--the roots that support short roots colonized by ectomycorrhizal fungi. Consequently, these various manipulations employed to aid the planting operation often increase ectomycorrhizal development.

The manner in which pine seedlings are lifted often determines how many ectomycorrhizae are retained on the seedlings. Years ago, when labor was cheap and plentiful, seedlings were lifted by hand. When properly supervised, this procedure caused little loss of second- and third-order lateral roots. Now we find sophisticated lifting machines being used almost exclusively because they save time and labor. Unfortunately, if the nursery soil is too wet or too heavy, machine lifting can cause dramatic loss of lateral roots and ectomycorrhizae.

Handling of seedlings during packing also causes loss of ectomycorrhizae on pines, especially if seedlings are graded. By omitting the grading prcedures, many nurseries have eliminated excessive drying of roots and the mechanical damage to fibrous roots caused by the additional handling. Seedling storage is usually necessary because most nurseries are too far from planting sites to lift and plant the same day. Modern tree nurseries have adequate refrigerated storage. If seedlings with good ectomycorrhizal development are packaged moist and stored properly at 3° to 5°C, the ectomycorrhizae will survive in an acceptable physiological condition for several months (Marx 1979).

Seedling abuse is probably most common at planting sites. You all have heard your share of horror stories: a seedling shipment is left in the sun to build up damaging heat in the seedling bags; a shipment is unlaoded and left exposed to freezing temperature too long prior to planting. Only too often, after the bags are opened, the roots are allowed to dry out before the seedlings are planted. Tree planters will strip the roots to make it easier to get the seedlings into the dibble hole or planting machine furrow.

Seedling tops may be well hardened-off and resistant to some rough handling, but root systems which have lost contact with soil are very easily damaged. Ectomycorrhizae are the first structures lost during mishandling.

After all this, reforestation specialists are surprised when mortality is 40 percent or more! When I view some of these operations, the mortality causes no surprise, the survival does. These old, clung-to practices, which come from either carelessness, ignorance, or simply complacence, should be modified or eliminated. With better planning, education, and supervision we can avoid practices which undermine quality planting.

CONTAINERIZED SEEDLINGS

If you accept our concept that pine seedlings with well-developed ectomycorrhizal root systems survive and grow better after outplanting, then containerization offers a unique opportunity for putting theory into practice.

Many of the problems mentioned can be avoided by planting properly grown container stock with suitable ectomycorrhizal development. Root pruning is not required with this stock. All roots and ectomycorrhizae developed in the plug are retained and remain intact at planting. Storage is generally no problem since container stock is held in the greenhouse or lath house until shipment time. Although container-grown seedlings are bulky to package and ship, they are usually less perishable than bare-root seedlings. The planting operation is easier because the seedling root system contained in the plug is of uniform size and shape. How can mycorrhizal development be encouraged in containers? Certain practices currently employed for growing containerized pines, such as heavy fertilizer applications and sterile growing media, often discourage ectomycorrhizal development (Marx and Barnett 1974). At the Institute for Mycorrhizal Development, we have developed satisfactory ectomycorrhizae on container-grown pines by altering these cultural practices and introducing selected fungal symbionts.

Ectomycorrhizal fungi are introduced into the growing medium in various ways. Inoculum in the form of duff, humus, infested soil, crushed sporophores, or excised mycorrhizal roots has been used with varying degrees of success. Although these methods normally ensure ectomycorrhizal development if cultural methods are modified, they also create problems. These inoculum forms often lack the most desirable fungi for the tree species and planting sites, and some contain various harmful microorganisms and noxious weeds. Mass production of pure culture inoculum is the best solution. Abbott Laboratories currently produces, for research purposes, a dried inoculum containing vermiculite, peat moss and *Pisolithus tinctorius*. This inoculum yields excellent results on containerized southern pines. This type of inoculum is preferred because it avoids the problems previously mentioned.

Results from some of our outplanting trials with container-grown southern pine colonized with *P. tinctorius* have been encouraging. The greatest improvement in survival and early seedling growth using seedlings tailored with this symbiont is exhibited on coal spoils and borrow pits.

CONCLUSION

Whether we are growing bare-root or containerized pine seedlings, we can say that any ectomycorrhizae on the roots of the planting stock are better than no ectomycorrhizae at all-- a conclusion based on 10 years of research at the Institute for Mycorrhizal Research and Development. *Certain species of ectomycorrhizal fungi are more* important to tree survival and growth under field conditions than other species. Much of our

Current research effort is aimed at finding the best combination of planting stock and fungal symbiont for a particular planting site.

Many of the points I have made were outlined by Wakely back in 1954. Little has been done since then to improve on *ideas* and *concepts* concerning site preparation, condition and care of seedling stock, and methods of planting as they affect initial survival of southern pines. Wakely also recognized that ectomycorrhizae are essential to good mineral nutrition of southern pines and pointed out that if ectomycorrhizae are lacking during the production of planting stock, inoculation should be tried.

Why, then, you may well ask, have I taken the trouble to mention these points again. Since ectomycorrhizal fungi occur naturally in such abundance in our nurseries and plantation sites, our best nursery stock usually develops luxuriant ectomycorrhizae prior to lifting; seedlings in the plantations become well colonized with ectomycorrhizal fungi indigenous to the site. I see our current nursery and planting programs for pines failing to address the problem of retaining ectomycorrhizae on planting stock and have attempted to convince you that pine seedlings well colonized with appropriate ectomycorrhizal fungi are ecologically adapted to better survive the rigors of outplanting.

Wakeley stated that the most widespread cause of low initial survival in southern pine plantations is not fire, animals, insects, or disease, but drought--drought in the sense of loss of more water from the tops than can be replaced through the roots. He concluded that the ability of planted seedlings to overcome drought and attain high initial survival seemed to depend upon formation of considerable new root tissue promptly after planting. I agree with this conclusion, and wish to add that ectomycorrhizal colonization of new root tissue aids in high initial survival. In fact, our findings at the Institute show a marked improvement in seedling survival if ectomycorrhizae are retained on the seedling roots at time of planting. If droughty conditions exist on the planting site, we advocate tailoring the seedlings with a fungal symbiont ecologically adapted to droughty conditions.

We are developing fumigation, inoculation, and fertilization procedures for tailoring seedlings with ectomycorrhizae synthesized by selected fungal symbionts produced in pure culture. Although these procedures increase the cost of the nursery operation, this cost is easily justified by the improved performance in outplantings. No one can afford to plant pine seedlings that have less than an excellent chance of surviving.

As knowledge accumulates about ectomycorrhizae on pines planted in the South, the options for nursery and plantation management can be better defined. The research task will be complete only when the costs of establishing and maintaining suitable ectomycorrhizae on plantable seedlings are accepted as the price we have to pay for acceptable survival and growth on newly established plantations.

Economists are continually evaluating the effectiveness and cost of various forestry operations--from seed collection to tree harvesting--to give advice about prudent investments for the future. Unfortunately, nursery operations and plantation establishment have not yet received adequate analytical treatment. It seems taken for granted that the technology of growing and planting trees simply exists, take it or leave it, and that the only major technological problem which policymakers are interested in is how to get X number of seedlings planted on Y number of acres. When the analysts get around to the economics of producing and planting pine seedlings, I think they will find that mycorrhizal technology is a pretty good investment.

Much of my presentation is speculative, but the answer to the question in my title is an emphatic "YES! The mycorrhizal condition of planted pines is important." The cost of assuring good mycorrhizal development in the nursery and retaining it until the seedlings are planted is not high. When one considers that the cost of seedlings represents only 8 to 12 percent of the total investment in reforestation, and that even in this juvenile stage the seedlings represent 100 percent of the potential financial return, then the potential benefits of improvements in seedling quality become evident.

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PISOLITHUS TINCTORIUS ECTOMYCORRHIZAE ENHANCE THE SURVIVAL AND GROWTH OF *PINUS TAEDA* ON A SOUTHERN APPALACHIAN COAL SPOIL[1,2]

R. F. Walker, D. C. West, and S. B. McLaughlin[3]

Abstract. A study was initiated to determine the significance of *Pisolithus tinctorius* ectomycorrhizae to the establishment and growth of loblolly pine (*Pinus taeda*) on sites disturbed in surface mining operations. Nursery grown seedlings infected with this fungal symbiont were outplanted on coal spoils in Tennessee. Treatments included seedlings infected with a mycelial inoculum of *P. tinctorius* and fertilized at the rate of 112 kg/ha NPK, control seedlings without *P. tinctorius* fertilized at an identical rate, seedlings infected with *P. tinctorius* but without fertilization, and control seedlings without *P. tinctorius* or fertilization. Seedlings infected with *P. tinctorius* survived better than control seedlings, but fertilization during the first growing season reduced survival irrespective of mycorrhizal treatment. Infection by *P. tinctorius* and fertilization resulted in the best seedling growth, while unfertilized control seedlings exhibited the least growth. Unfertilized seedlings infected with *P. tinctorius* and fertilized control seedlings exhibited growth intermediate to that of the other treatments. It appears that an ectomycorrhizal infection of loblolly pine by *P. tinctorius* can enhance survival and growth on these adverse sites and reduce the need for fertilization.

INTRODUCTION

Nursery grown pine seedlings have been used in many surface mine reclamation programs in the eastern United States. The adverse growing conditions encountered on these sites, such as low pH, low nutrient status, high concentrations of toxic substances, elevated surface temperatures, and droughtiness have contributed to a generally poor performance by these seedlings. Much research has been directed toward improving artificial regeneration techniques to provide a greater degree of success. The inoculation of seedlings in the nursery with an ectomycorrhizal fungus offers promise as a viable aid in establishing pine on adverse sites.

The importance of ectomycorrhizae to the growth of pine in natural forest soils is well recognized. Many species of ectomycorrhizal fungi infect the roots of pine in normal forest soil environments (Marks and Kozlowski, 1973). Under stress conditions, such as those that often prevail on surface mine sites, certain of these fungi appear superior in their ability to survive and provide benefits to their hosts. Many workers (Hile and Hennen 1969, Lampky and Peterson 1963, Marx 1975, Medve et al. 1977, Schramm 1966) have reported the occurrence of basidiocarps of *Pisolithus tinctorius* (Pers.) Coker and Couch associated with several tree species on various coal spoil sites. It is logical to assume that *P. tinctorius* ectomycorrhizae contributed significantly to the survival and growth of these early colonizing host species.

Experimental techniques have been developed to artificially inoculate pine seedlings in the

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nursery with pure cultures of P. tinctorius (Marx 1969, Marx and Bryan 1975). Inoculated seedlings have been shown to be superior to uninoculated seedlings in the nursery (Marx and Bryan 1975, Marx et al. 1976), on routine reforestation sites (Marx et al. 1977), and on adverse sites (Berry and Marx 1978, Marx and Artman 1979). The evidence suggests that the artificial inoculation of pine seedlings in the nursery with P. tinctorius will promote sufficient ectomycorrhizal development to provide these seedlings a significant advantage over those grown by conventional methods.

Many coal spoils, including those that are not acid, are difficult to revegetate because they are deficient in one or more of the essential plant nutrients (Vogel 1975). Most mine spoils in the Appalachian region are deficient in plant-available nitrogen and phosphorus (Plass and Vogel 1973). Nitrogen and phosphorus amendments are usually essential for the successful establishment and growth of vegetation on such sites. Several workers (Bengtson et al. 1973, Zarger et al. 1973) have shown the value of fertilization to the survival and growth of various pine species on coal spoils in the southern Appalachians. More recently, Berry (1979) provided evidence that the use of starter fertilizer tablets improved initial growth of loblolly pine on badly eroded sites in the Tennessee Copper Basin.

The study reported here was designed to determine the significance of P. tinctorius ectomycorrhizae to the successful establishment of loblolly pine (Pinus taeda L.) on coal mine spoils in Tennessee. Due to the demonstrated response of pine seedlings to fertilization on these adverse sites, a fertility variable was introduced to allow examination of the interrelationships of P. tinctorius ectomycorrhizae and fertilization as they affect survival and growth. It is believed that an infection of loblolly pine with this fungal symbiont can reduce the need for the application of nutrient amendments on coal spoils in the southern Appalachians.

MATERIALS AND METHODS

The P. tinctorius inoculum used in this study was produced by the Institute for Mycorrhizal Research and Development (IMRD) of the USDA Forest Service 4/ by the methods of Marx (1969) and Marx and Bryan (1975). It consisted of fungal mycelia grown on a vermiculite-peat moss-nutrient media substrate such that the hyphae penetrated between the layers of the vermiculite particles. The inoculum was leached with cold tap water prior to application in the nursery.

The P. tinctorius inoculated seedlings and the control seedlings used in this study were grown by the Weyerhaeuser Company 5/ by the methods of Marx and Bryan (1975). Nursery beds were fumigated with 392 kg/ha of MC-2 6/ three weeks prior to seeding. Fertilizer and lime were applied to the beds at the rate of 560 kg/ha of 10-20-10 and 1120 kg/ha dolomitic limestone. The P. tinctorius inoculum was applied at 1076 ml/m^2 of soil surface and incorporated into the bed. Other beds were left to become infested by naturally occurring ectomycorrhizal fungi for the production of control seedlings. Stratified seeds (McCurtain County, Oklahoma seed source) were coated with Arasan 7/ and planted in April, 1977. Three applications of $(NH_4)_2SO_4$ were applied in 2 week intervals at the rate of 112 kg/ha/application beginning in June, 1977. The seedlings were lifted in January, 1978 and graded to a height of 15 cm and a root collar diameter of 3 mm. Ten seedlings were randomly selected from both the inoculated and control nursery beds and evaluated by the IMRD for ectomycorrhizal development. All seedlings were stored at $5^{\circ}C$ for 2 months prior to outplanting.

The outplanting site was a coal spoil located in Campbell County, Tennessee. All mining ceased in the fall of 1977 and the spoil was returned to approximate original contour. A straw mulch was applied and the site was hydroseeded with a mixture of Kentucky 31 tall fescue (Festuca arundinacea Schreb.), perennial ryegrass (Lolium perenne L.), and Korean lespedeza (Lespedeza stipulacea Maxim.). Five replicate blocks, each with four 5x5 m plots, were established on the site. A 6 m wide border separated each plot. One of four treatments was randomly assigned to each of the four plots within a replicate block. The treatments in this random block design were seedlings infected with P. tinctorius and fertilized at a rate of 112 kg/ha NPK, control seedlings without P. tinctorius fertilized at an identical rate, seedlings infected with P. tinctorius but without fertilization, and control seedlings without P. tinctorius or fertilization. Twenty-five seedlings were planted by hand in each plot in five rows of five seedlings each. The spacing of seedlings within and between rows was approximately 1.25 m. Five spoil samples were obtained

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6,7/ The use of these products does not constitute an advocacy of them on the part of the Oak Ridge National Laboratory.

from each plot at a depth of 0 to 20 cm, combined into one composite sample per plot and chemically analyzed. One hundred fourteen g of 15-15-15 fertilizer was evenly distributed over 0.37 m^2 around each of the appropriate seedlings to achieve the fertilizer equivalent of 112 kg/ha NPK.

At planting, measurements of height and root collar diameter were taken of each seedling. Survival, height, and root collar diameter measurements were taken in March, 1979 and March, 1980. Height and root collar diameter growth measurements were expressed as relative growth indices by subtracting the initial measurement from the second year measurement and dividing by the initial measurement. Growth parameters expressed in this manner compensate for initial differences in seedling size and variation in planting depth. Similarly, the plot volume index (PVI) of Marx et al. (1976) was expressed on a relative basis (RPVI) by subtracting the initial PVI from the second year PVI and dividing by the initial PVI. All data were subjected to analyses of variance.

RESULTS

The seedlings inoculated in the nursery with *P. tinctorius* had 15 percent of their feeder roots infected with this symbiont and 17 percent infected with naturally occurring ectomycorrhizal fungi, primarily *Thelephora terrestris* Ehrh. ex Fr. The total ectomycorrhizal infection of the inoculated seedlings was 32 percent, and 90 percent of the seedlings examined were infected with *P. tinctorius*. The control seedlings had 35 percent of their feeder roots infected with naturally occurring ectomycorrhizal fungi, primarily *T. terrestris*. None of the control seedlings examined were infected with *P. tinctorius*.

The chemical analysis of the spoil samples collected at planting revealed that the plots were fairly uniform with respect to most of the parameters tested. The means for all plots were pH 6.0; 3.1 percent organic matter; and 15, 12, 120, 1308, 308, 187, 340, 12, and 136 p/m, respectively, of NO_3, P (weak bray), K, Ca, Mg, SO_4, Fe, Al, Zn, and Mn. 8/ This spoil was typical of those found in the southern Appalachians with a low P level and high levels of SO_4, Fe, and Al. It was atypical in that the pH was moderately high and there was a high level of Ca.

The survival of loblolly pine seedlings was significantly affected (P=0.10) by an infection with *P. tinctorius* and by fertilization (Table 1). Two years after outplanting, seedlings infected with *P. tinctorius*, independent of fertilizer treatment, had 32 percent greater survival than control seedlings. Conversely, fertilization reduced survival irrespective of ectomycorrhizal treatment by 45 percent. The interaction of the two treatments resulted in some moderation of their opposite effects, but there was a persistent increase in survival associated with an infection by *P. tinctorius*. Fertilized seedlings with *P. tinctorius* had 74 percent greater survival than fertilized control seedlings and unfertilized seedlings with *P. tinctorius* had 15 percent greater survival than seedlings without *P. tinctorius* or fertilizer.

Table 1. Survival, growth, and relative growth of loblolly pine with or without *P. tinctorius* and with or without fertilizer after two years on a coal spoil in Tennessee.

Treatment	Percent Survival	Height	Root Collar Diameter	PVI
		Growth		
		cm	mm	cm^3
P. tinctorius	75	18.4	2.9	448.6
Control	57	14.6	2.1	219.6
Fertilized	47	23.0	3.7	390.8
Unfertilized	85	13.3	1.9	277.4
P. tinctorius Fertilized	59	24.6	4.1	603.4
P. tinctorius Unfertilized	91	14.4	2.0	293.8
Control Fertilized	34	20.2	3.1	178.2
Control Unfertilized	79	12.2	1.7	260.9
		Relative Growth		
P. tinctorius		1.1	0.7	5.0
Control		0.9	0.5	2.1
Fertilized		1.6	0.8	3.6
Unfertilized		0.8	0.5	3.5
P. tinctorius Fertilized		1.4	0.9	5.7
P. tinctorius Unfertilized		1.0	0.5	4.3
Control Fertilized		1.3	0.7	1.6
Control Unfertilized		0.7	0.4	2.7

8/ Chemical analyses were done by A&L Agricultural Laboratories, Inc., 2176 Dunn Avenue, Memphis, Tennessee 38114

Seedling growth was also significantly affected (P=0.10) after 2 years by an infection with *P. tinctorius* and by fertilization (Table 1). Unlike survival, both treatments resulted in increased growth. Independent of fertilizer treatment, the relative height growth of seedlings infected with *P. tinctorius* was 22 percent greater and the relative root collar diameter growth 40 percent greater than that of the control seedlings. These growth differences became more apparent when combined with survival in the relative plot volume index. The RPVI of seedlings with *P. tinctorius* was 138 percent greater than that of the seedlings without *P. tinctorius*. Greater differences in growth resulted from fertilization. Fertilized seedlings, independent of ectomycorrhizal treatment, had a relative height and root collar diameter growth 100 and 60 percent greater, respectively, than that of the unfertilized seedlings, but the RPVI was only 3 percent greater, reflecting the low survival associated with fertilization. The interaction of the two treatments produced similar results. The relative height growth of the fertilized seedlings with *P. tinctorius* was 8 percent greater and the relative root collar diameter growth 29 percent greater than that of the fertilized seedlings without *P. tinctorius*. The subsequent 256 percent difference in RPVI reflected the increased growth and survival due to *P. tinctorius*, but the difference was accentuated by the extremely poor survival of the fertilized control seedlings. Alternately, the relative growth in height, root collar diameter, and PVI of unfertilized seedlings with *P. tinctorius* was 43, 25, and 59 percent greater, respectively, than that of the seedlings without *P. tinctorius* or fertilizer.

DISCUSSION

It can be concluded that *P. tinctorius* ectomycorrhizae significantly improved the survival and growth of loblolly pine seedlings on coal spoils. This ecologically adapted fungal symbiont provides the host a greater physiological tolerance of the adverse conditions prevalent on these sites. It is believed that the increased capacity for the absorption of moisture and nutrients afforded by *P. tinctorius* was of particular importance in this study due to competition with the grasses planted on the spoil. The establishment of a grass cover, required by most state reclamation laws, provided a degree of realism in that it presented a competition variable often ignored in reclamation studies. The results of this study indicate that the seedlings infected with *P. tinctorius* were superior in their ability to survive and grow under these conditions.

Fertilization was found to be both a positive and a negative factor in the establishment of pine on this site. Seedling growth was enhanced by this treatment but survival was substantially reduced. Several possible explanations exist for the relatively poor survival of fertilized seedlings. The application of fertilizer to the spoil surface stimulated grass growth, resulting in increased competition for moisture and nutrients. In some instances, the grass overtopped the seedlings. It is also probable that fertilization during the first growing season stimulated excessive top growth, which the root system was physiologically incapable of supporting. The problem of an undesirably high top/root ratio would be accentuated by the competition factor. It is apparent that further research is warranted with respect to the rate and timing of fertilizer applications to coal spoils when both ground cover and seedling establishment are desired.

A consideration of the interaction of the two treatments indicates that either of the treatment combinations with *P. tinctorius* ectomycorrhizae were superior to those with control seedlings. Unfertilized seedlings with *P. tinctorius* was the combination of treatments producing results most closely approximating commonly accepted reclamation objectives, i.e. maximization of site protection and productivity. Although the fertilized seedlings with *P. tinctorius* exhibited greater initial growth, the fertilizer-induced lower survival of this combination renders it less desirable. It is probable that an adjustment in the timing and rate of fertilizer applications would enable the seedlings to derive maximum benefit from both *P. tinctorius* ectomycorrhizae and fertilization. Research is needed to further delimit the fertilizer variable such that the enhanced survival and growth afforded pine seedlings on coal spoils by an infection with *P. tinctorius* is not compromised to the detriment of overall establishment success.

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DEVELOPING FUSIFORM RUST-RESISTANT SEED ORCHARDS USING SURVIVORS OF ARTIFICIAL INOCULATION TESTS[1]

H.R. Powers, Jr.[2]

Abstract.--The healthy survivors of artificial inoculation tests were planted in fusiform rust-resistant seed orchards. After 3 years of exposure to natural infection in field plantings, trees in the most resistant families had less than 10% infection. Using survivors extends the genetic base of rust-resistant material currently available and also increases the level of resistance in rust-resistant orchards.

INTRODUCTION

Fusiform rust, caused by Cronartium quercuum (Berk.) Miyabe ex Shirai f. sp. fusiforme, is the most serious disease of loblolly (Pinus taeda L.) and slash (P. elliottii var. elliottii Engelm.) pine in the southern United States (Phelps 1973, Powers et al. 1975). Recent estimates of damage caused by this disease exceed $110 million annually due to both mortality and quality loss of forest products. In many areas of the South, management practices such as intensity of site preparation, choice of species for planting, planting density, and type of product to be produced, are determined by the severity of this disease. In the past, effective controls have been limited to the use of fungicidal sprays in forest tree nurseries, pruning infected limbs, and excising stem cankers on high-value ornamental and seed orchard trees. Effective control in the forest, however, depends upon the development of disease-resistant strains of pine (Powers et al. 1979).

Most forest industries and state forestry organizations in the area of the South most seriously affected by this disease are developing seed orchards for the production of rust-resistant seedlings. Genetic resistance in both slash and loblolly pine has been demonstrated (Jewell 1964, Zobel et al. 1971), and superior trees with resistance have been selected. The rust-resistant orchards were developed by the standard practice of making grafts from the selected rust-resistant trees. Unfortunately, the number of proven rust-resistant clones is relatively low, particularly in loblolly pine. Therefore, the genetic base of these orchards needs to be expanded by any means possible.

Progeny of most resistant clones have already been tested for rust resistance by artificial inoculation in greenhouse tests. The first greenhouse tests were made in 1971, and it was felt at that time that the healthy survivors of these inoculations were promising genetic material for future use in rust resistance work. Our objective was to determine the most effective use of inoculation test survivors in an overall program for the development and breeding of rust-resistant pines.

MATERIALS AND METHODS

The seedlings were inoculated by using the concentrated basidiospore spray (CBS) inoculation system (Matthews and Rowan 1972). This procedure allowed for the standardized evaluation of large numbers of pine seedlings under controlled conditions. Evaluations were completed in 6 to 9 months, and the healthy survivors were transferred to containers and grown in the greenhouse for several months prior to establishment in the field. The standard field planting design was a randomized

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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block, with eight replications. Each replication contained a 10-tree row, planted in random order, of each family included in the study.

During the next few years clones with higher levels of resistance, as well as the progeny from some of the first controlled pollinations between resistant parents, became available for testing. With this improved material available, it was decided in 1974 to establish a seed orchard for the production of rust-resistant seedlings. Half of this new orchard was established as a standard clonal orchard, with the remainder designed as a seedling seed orchard using the survivors of the most resistant families from the artificial inoculation tests. The rust-resistant seed orchard of 60 acres is one of the largest in the southern United States, and the first to include seedling orchard blocks developed by use of inoculation tests survivors.

Each seedling seed orchard block contained 50 replications. Each replication included a single tree, placed at random, of each family included in the block. Usually 12 to 16 half- or full-sib families were used in each block. The basic principal of the seedling seed orchard is to space the trees very close together, in our case 5 x 15 feet. In order to reach an eventual spacing of approximately 30 x 30 feet, over 90 percent of the original seedlings must be removed. This means about 5 seedlings of the original 50 of each family will remain as crop trees. The first removals are those trees that become diseased by natural infection after they were planted in the field. Subsequent removals were based on growth and form characteristics, and on family history regarding rust resistance. Data were taken on rust infection, height, and growth characteristics the third year after planting and every year thereafter.

RESULTS

Progeny Test Blocks

The earliest results obtained using the survivors of artificial inoculation tests came from progeny test blocks. After 6 growing seasons in the field, the incidence of fusiform rust on these survivors ranged from 0 to 49% (Table 1). The controls, which were commercially available seedlings from a state nursery, had 74% infection. The height of various half-sib families in the test ranged from 11.3 feet for a loblolly x shortleaf hybrid to 16.8 feet for family 11-16 (Table 1).

Scions were collected from the best individuals among the 80 members of each family in this progeny test to make grafts for clonal seed orchards. Most of these new selections were from families with the least incidence of rust, although outstanding individuals in families with higher levels of rust infection were included to expand the genetic base of available material. Even the individuals from families with somewhat lower levels of rust resistance had survived both severe greenhouse inoculations and 6 years of natural infection in the field. In addition, some of them were among the tallest trees in the test. However, there was no direct correlation between average height and overall incidence of rust among the survivors in this test. Family 11-16 had the tallest average height in the test and was intermediate in rust incidence (21% infection), ranking 8th out of 12 families in the test.

Seedling Seed Orchard Blocks

The first seedling seed orchard blocks were planted in 1975. These blocks included inoculation test survivors from 16 half- and full-sib families rated intermediate to good for rust-resistance following greenhouse tests. After 3 years exposure to natural field infection, the families ranged from 2 to 47% infection (Table 2). No susceptible checks were included in the orchard blocks. There was a good correlation between the results from the artificial inoculation tests and subsequent natural infection on the survivors in the field. For example, the first 10 families listed in Table 2 were consistently among the most resistant in artificial inoculations, and survivors of these families all had 10% or less infection after 3 years exposure in the field. The next 5 families were intermediate in greenhouse test and ranged from 16 to 36% infected in the field. Family 10-31, the most heavily infected in the field at 47%, was a marginal candidate for inclusion in this planting since in two artificial inoculation tests it had only 25% less infection than the susceptible checks.

Height measurements were taken after 4 years. Averages for the tallest 10 trees of each family were used since this would be the group from which selections probably would be made for eventual crop trees. These averages for each family ranged from 7.4 feet for a shortleaf hybrid to 13.9 feet for two selections from Florida (Table 2). After 4 growing seasons, at least 20 individuals remained from the original 50 in the case of 15 out of 16 families included in the block. These trees represent the most resistant portion of each family, and will provide an adequate number for selection of final crop trees in this orchard block.

DISCUSSION

When survivors of artificial inoculation tests are planted in the field, in either progeny test blocks or in seedlings seed orchard blocks, they are again subjected to a vigorous screening for rust resistance. Individuals that have survived a heavy artificial inoculation in the juvenile stage as seedlings, and up to 6 years of exposure to natural infection in the field, should be some of the most resistant material currently available.

Most progenies tested for rust resistance by artificial inoculations were open-pollinated seed obtained from seed orchard trees, or from trees in clone banks were superior selections were grouped together for evaluation prior to being included in rust-resistant seed orchards. It is likely that the pollen parents of the seedlings being tested are also improved genetic material, since they also were located in the orchards or clone banks. In addition, most seedlings in inoculation tests were members of half-sib families, with many pollen parents involved in the crosses. Therefore, these seedlings represent a broader genetic base than the grafts in clonal orchards, since they were derived from a large number of parents. The parents involved in these crosses included most of the rust-resistant selections available at this time, as well as other trees in the orchards that have other favorable characteristics.

The most obvious immediate use of the best individuals among the survivors in these plantings would be as new selections to provide scion material for grafting and inclusion in new clonal orchards. In addition, as the individuals in the progeny test blocks and the seedling seed orchard mature and begin to produce seed, their progeny can again be screened for resistance and the cycle repeated with a new generation of survivors.

The material established in both the clonal and seedling seed orchard blocks are already producing a few cones. A sufficient number of cones should be available within 4 to 5 years for the production of approximately one-half million rust-resistant seedlings. Since both clonal and seedling seed orchard blocks were used to establish the rust-resistant orchard, it will then be possible to determine which type of orchard produces seed with the highest levels of rust resistance.

Eventual production from the 60-acre seed orchard should reach approximately 6 million seedlings annually for use in high rust-hazard areas. It is hoped that the first generation seed orchard blocks will produce seedlings that will reduce the average incidence of rust in slash pine by 50% and in loblolly pine by 40%. Successive generations of seedling seed orchard blocks, including the most resistant of the survivors from the first generation orchards, should eventually reduce the overall incidence of rust to approximately 25% of that in currently available commercial seedlings.

Table 1.--Fusiform rust infection (after 6 years) and average height of 13 loblolly families in "survivor" progeny test block 301.

Family	Rust infection	Average height
	Percent	Feet
SML-9	0	13.3
Hit Hy	3	11.3
10-6	7	13.4
11-9	10	14.6
LP	15	15.0
11-20	18	13.5
10-5	18	14.8
11-16	21	16.8
L29R	26	12.8
1582-11	29	13.7
4625-3	30	14.6
1590-6	49	14.8
Check	74	14.1

Table 2.--Fusiform rust infection (after 3 years) and height growth (after 4 years) of 16 loblolly families in the rust-resistance seedling seed orchard block 151.

Family	Rust Infection	Average height of tallest 10 trees
	Percent	Feet
29-Rx1495-35	2	12.7
SML-9	2	11.4
11-9	6	11.8
TDR	6	13.0
TFS	6	13.5
42R	7	12.9
H.H.	7	7.4
11-20	7	11.5
1495-35	9	11.3
10-5	10	13.6
15-42	16	13.2
2318	19	13.1
T-605	21	13.9
T-601	25	13.9
29R	36	11.4
10-31	47	12.5

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LATENT FUSIFORM RUST INFECTIONS IN SLASH AND LOBLOLLY PINE NURSERY STOCK[1/]

S. J. Rowan[2/] and David Muse[3/]

Abstract.--Significant numbers of slash and loblolly pine seedlings with fusiform rust infections do not display symptoms before they are lifted from nursery beds. Latent infected seedlings are planted in new plantations at rates that are related to infection levels observed at time of lifting from nursery seedbeds. Since galls develop more slowly in loblolly than in slash pine, the problem is greater with this species.

Fusiform rust, caused by Cronartium quercuum (Berk.) Miyabe ex Shirai f. sp. fusiforme (Cumm.) Burdsall & Snow, is the most serious disease of planted slash (Pinus elliottii Engelm.) and loblolly pines (P. taeda L.), and its incidence in new plantings is increasing (Schmidt et al., 1974). Despite fungicidal spraying to minimize infection in nurseries, an average of 2.5 percent of the slash and loblolly pines produced each year in southern nurseries have visible rust galls in December (Rowan, 1977). Czabator (1971) recognized that some proportion of the seedlings examined at lifting may have undetectable, latent infections. Since these seedlings are very likely to die after they are outplanted, it would be useful to know how common the phenomenon of latent infection is.

In this paper we report an exploratory study in which the rate of gall development was monitored monthly in both greenhouse and nursery grown slash and loblolly pine seedlings.

METHODS

Seedlings of both slash and loblolly pines were artificially inoculated with the fusiform rust fungus in May, and 31 replicates of each species were retained in greenhouse culture and 42 replicates of each species were placed on a nursery seedbed. The inoculation was equivalent to heavy natural exposure. A replicate consisted of 25 seedlings in a 6-inch plastic pot. The pots were arranged in both the greenhouse and nursery in a randomized complete block design with three blocks. Natural rust infections were minimized by selecting a nursery with a low rust hazard rating (Georgia Forestry Commissions' Hightower Nursery) and by spraying all seedlings placed within the nursery 3 times each week from May through July 7 with ferbam formulated with a spreader sticker and applied at the rate of 3 pounds per acre in 75 gallons water.

Starting in July, seedlings were examined monthly, and the percentage of seedlings with galls was recorded. To determine the percentage of seedlings with latent infections in any month, the infection percentage for that month was compared with that at 16 months after inoculation. To determine if significant numbers of natural infections were established in nursery grown seedlings and to minimize the possibility that additional latent infections existed in seedlings 16 months after inoculation, 3 replicates were returned to the greenhouse at monthly intervals beginning 3 months after inoculation and these were compared to the greenhouse grown seedlings. As soon as definite galls were present on seedlings, they were removed from the pot by cutting at groundline. This provided additional room in the pots for growth of the remaining seedlings. Final readings were made 16 months after inoculation of both the greenhouse and nursery grown seedlings.

The data were somewhat characteristic of growth curve data and were analyzed using the following indexed growth model:

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$$Y_{ij} = \alpha_i + \beta e^{-\gamma(T_{ij} - K)} + \varepsilon_{ij}$$

Where Y_{ij} denotes the percentage of galled seedlings observed for the i^{th} block (replicate) at the j^{th} point in time, α_i is the maximum percentage of galled seedlings expected for the i^{th} block, β is the degree of slope, $e = 2.7183$, γ is weighted factor for the exponential term, K is a correction factor, T_{ij} denotes time after inoculation in months, and ε_{ij} denotes the error term for the i^{th} block and j^{th} point in time.

RESULTS AND DISCUSSION

Although all seedlings in this study were inoculated on the same day with equal numbers of basidiospores of the fusiform rust fungus, the rate of gall development was markedly affected by the environment in which the infected seedlings were grown during the 16 months after inoculation (Table 1). On seedlings grown in the greenhouse, symptoms of gall development first appeared 2 months after inoculation. Easily detectable galls were first observed in greenhouse grown seedlings 3 months after inoculation, but nursery grown seedlings failed to show these symptoms until 6 months after inoculation (equivalent to observations in November). Thus, rust infections may not be apparent in nursery seedbeds until November.

Using the data obtained in this study and the above nonlinear growth curve model, a least squares analyses of the data produced the following results:

1. Nursery grown slash:

   $$\hat{\alpha} = Y + 3.522\ e^{-.37(T - 11)}$$

   where $\hat{\alpha}_1 = 82.2$, $\hat{\alpha}_2 = 88.6$, $\hat{\alpha}_3 = 84.4$,

   $6 \leq T_{ij} \leq 16$;

2. Nursery grown loblolly:

   $$\hat{\alpha} = Y + 10.038\ e^{-.24(T - 11)}$$

   where $\hat{\alpha}_1 = 79.3$, $\hat{\alpha}_2 = 83.6$, $\hat{\alpha}_3 = 77.5$,

   $6 \leq T_{ij} \leq 16$;

3. Greenhouse grown slash:

   $$\hat{\alpha} = Y + 5.515\ e^{-.18(T - 7)}$$

   where $\hat{\alpha}_1 = 89.2$, $\hat{\alpha}_2 = 81.8$, $\hat{\alpha}_3 = 87.7$,

   $3 \leq T_{ij} \leq 12$;

4. Greenhouse grown loblolly:

   $$\hat{\alpha} = Y + 2.731\ e^{-.35(T - 7)}$$

   where $\hat{\alpha}_1 = 74.7$, $\hat{\alpha}_2 = 79.6$, $\hat{\alpha}_3 = 75.2$,

   $3 \leq T_{ij} \leq 12$.

In these equations, $\hat{\alpha}$ is the final infection percentage, and Y is the infection percentage T months after inoculation.

Although these equations fit the observed data rather well, their value for prediction is unproven. The equations were generated from data on seedlings whose final infection rates were 84 percent for slash pine and 76 percent for loblolly pine. At the much lower infection rates in protected nurseries, completely different relationships may exist. Table 1 and the equations, however, indicate that large numbers of seedlings that will eventually develop galls appear healthy in November and December, when southern nurseries typically begin lifting and shipping seedlings.

Table 1.--Percentages of fusiform rust galled seedlings observed in slash and loblolly pine when grown in greenhouse or nursery seedbeds by both month after seedlings were artificially inoculated and calendar month.

Months after inoculation	Month	Galled seedlings Nursery grown Slash	Galled seedlings Nursery grown Loblolly	Galled seedlings Greenhouse grown Slash	Galled seedlings Greenhouse grown Loblolly
		------------	Percent	------------	
2	July	0.0	0.0	0.5	0.3
3	Aug.	0.0	0.0	74.9	65.7
4	Sept.	0.8	0.2	76.6	68.0
5	Oct.	1.7	4.5	78.3	71.0
6	Nov.	62.6	46.4	80.0	73.3
7	Dec.	70.6	55.9	80.9	74.1
8	Jan.	73.9	59.0	81.7	74.5
9	Feb.	75.6	60.9	82.1	74.9
10	March	80.7	65.7	82.5	74.9
11	April	82.5	72.6	83.8	76.0
12	May	83.5	74.5	84.2	76.4
13	June	83.7	74.7	84.2	76.4
14	July	83.9	74.9	84.2	76.4
15	Aug.	83.9	75.7	84.2	76.4
16	Sept.	84.0	76.0	84.2	76.4

Since galls developed more slowly on loblolly than on slash pine, the number of latent infections was larger on loblolly pine. The equation indicates that loblolly pines have 10.7 percent more latent infections than slash pine in December.

In view of the high investment in seedlings after they leave the nursery, additional study of the rate of gall development seems justified. We are planning a study in which the equations presented here will be tested on seedlings with a wide range of infection percentages. This study should provide a means of predicting the final fusiform rust infection percentages in slash and loblolly pine stocking from observations made at the time seedlings are lifted from the nursery seedbed.

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IMBIBITION TEMPERATURES AFFECT SEED MOISTURE UPTAKE, GERMINATION, AND SEEDLING DEVELOPMENT[1/]

James P. Barnett[2/]

Abstract.--Temperatures of seed and water during imbibition of southern pine seeds can affect seed germination and seedling development. Temperatures also affect rate of moisture uptake and when germination begins. Imbibition temperatures had little effect on longleaf and slash pine germination and seedling development. But loblolly pine was affected by absorption temperatures, and the effects varied greatly by single-tree lots.

INTRODUCTION

Temperatures at which seeds absorb water have an important effect on germination and early seedling growth of several agronomic species (Pollock and Toole 1966, Hobbs and Obendorf 1972). Imbibition temperatures lower than 75° F often harm these species. In lima beans an important part of this temperature sensitivity is related to initial seed moisture (Pollock 1969); when seed moisture was below 13 percent at the time absorption started, survival and seedling vigor decreased. But this relationship probably does not exist in pine seeds; they typically require drying to moisture contents lower than 13 percent so that storability will be maintained. We know little about how absorption temperatures affect pine seed germination and seedling growth. But light exposures during stratification, and presumably in the absorption phase, do increase speed of germination of loblolly pine (*Pinus taeda* L.) seeds (McLemore 1964).

The conditions under which water absorption takes place in pine seeds are usually ignored, but current stratification techniques make control of these conditions easy (Hosner et al. 1959, Barnett 1971). I have begun a series of tests to evaluate how imbibition temperature and light regimes affect germination and early seedling development of southern pines. Early tests showed that temperatures during moisture uptake significantly affect loblolly germination and seedling development, and the response varies greatly with individual seed lots[3/]. Because of these positive results, I did more testing of temperatures of seed and water during imbibition.

METHODS

I used three composite local seed lots each of loblolly, slash (*P. elliottii* Engelm.), and longleaf (*P. palustris* Mill.). And I used several half-sib lots of loblolly seed in supplemental tests. The initial seed moisture contents ranged from 6 to 10 percent. Empty seeds were removed by flotation (Barnett and McLemore 1970). The 20 treatments were combinations of five absorption temperatures (48°, 60°, 72°, 84°, and 96° F), two light levels during absorption, and two during germination. Light levels during absorption and germination were total darkness and 1300 lux from cool-white fluorescent bulbs. Darkness was maintained in lightproof cloth bags. Light was continuous during absorption, but during germination I used a 16-hour photoperiod. I soaked seeds in germination dishes by placing them at the desired temperature and then moistening the Kimpak germination medium with water at the same temperature.

During imbibition, I measured rate of moisture uptake by providing extra seeds from each of three replications for sampling of moisture content. These tests were run for 96 hours. Moisture content was expressed on a dry-weight basis after seeds dried at 180° F for 24 hours.

All germination tests were conducted at 72° F after seeds had been soaking for 48 hours at the prescribed temperatures. Duplicate 100-seed samples were tested for each replication for 28 days. As germination began and radicles extended about 1/2 inch, 40 seedlings from selected treatments were transplanted into styroblock containers filled with a peat-vermiculite medium. When seedlings were 12 weeks old, I measured total dry weight, then analyzed statistical differences at the 0.05 level in a completely randomized design.

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RESULTS

Moisture Uptake

Water absorption was closely related to temperature during the early periods of moisture uptake, but the absorption pattern was different for each species (table 1). Loblolly seeds absorved moisture faster at the higher temperatures during the first 24 hours of uptake. After 48 hours not much more absorption took place and maximum moisture contents reached 35 percent. This is the highest that moisture contents of loblolly seeds will get before seedcoats rupture and germination begins (Barnett 1976).

The rate of moisture uptake was greater in slash pine seeds than in loblolly, and it leveled off only after longer exposures to high temperatures. Higher temperatures again speeded absorption. At 48°, 96 hours were needed for the seed to reach 40 percent moisture content. But at 84° or 96° this same moisture level was reached in 24 hours (table 1). Seedcoat rupture and germination of slash seeds began at a moisture content of about 40 percent. After the longer periods of exposure to the higher temperatures, rate of absorption declined. Apparently absorption did not continue because temperatures were too high for seedling development.

Longleaf seeds absorbed moisture at about the same rate as slash seeds, but absorption went on longer. At a moisture content of about 55 percent, seedcoat rupture and germination began; moisture levels of seeds imbibed at 72° reached 75 percent after 96 hours. But the absorption rate of seeds imbibed at higher temperatures declined, again probably because seedling development is not normal at such temperatures. Other studies have shown that high temperatures adversely affect development of germinating seeds (Barnett 1979).

The absorption data support earlier results suggesting that seedcoats restrict the quantity of uptake by limiting how much the megagametophyte and embryo can expand (Barnett 1976). Of course the less dormant seeds are least restrained by the seedcoats. Loblolly seeds are most dormant, then slash, then longleaf.

Germination

Temperature and light conditions during 48 hours of absorption had statistically significant, but relatively unimportant, effects on germination (table 2). Imbibition at 96° did lower germination in all three species. Only in loblolly pine was there any difference due to light condition; at 72° germination in the dark was lower than at all other combinations of light and temperature.

The treatment effects on germination values, which reflect speed and completeness of germination (Czabator 1962), followed the same trends established for germination percentages. Absorption at 96° reduced germination values for all species (table 2). Seeds of slash and longleaf pine soaked at 48° had lower values than those soaked at 72°, so the germination rate was slower. Loblolly germination values were affected by both light and temperature regimes. Seeds soaked at 60° in light had greater germination values than all other treatments, but the differences were too small to be of practical importance.

Because absorption conditions affected germination of loblolly seed more than they affected the other species, I did supplemental tests with single-tree lots of loblolly seeds. Light conditions during imbibition markedly affected germination when tests were made in the dark (fig. 1). Germination in the dark was higher when seeds had soaked under light. It also increased as absorption temperatures increased.

Germination in light was unaffected by the light level during absorption. But temperature of moisture uptake did affect germination, and the response varied greatly by seed lot (fig. 1). In lot 1, high temperatures resulted in lower germination. Seeds of lot 2 germinated better when soaked in light at 96°. Lot 3 seeds were least affected by conditions of moisture uptake.

Seedling Development

Light levels during absorption did not affect seedling development, but temperatures did (fig. 2). No differences in seedling weights due to temperature of water absorption were detectable in longleaf and slash pines, probably because of the wide variation within treatments. Loblolly seedlings were affected by absorption temperature--dry weights were greater for 84° than for 48°. Supplementary tests with single-tree lots of loblolly pine again showed a wide variation in dry weights among seed lots. No effect of soaking temperature on seedling development occurred consistently.

CONCLUSIONS

Recognition of the physical nature of water uptake has long been accompanied by the assumption that little of biological interest happens during this relatively short period. So, many studies of pine seed germination start with soaked or partly imbibed seeds, and little information is provided on the conditions under which this moisture is absorbed. Results of this study show, however, that the temperature at which water absorption occurs can affect seed germination and seedling development. Response varies greatly by single-tree lots. More research is needed so we can critically evaluate the process involved, particularly in loblolly pine where the effects are the greatest.

Table 1.--Average moisture contents of loblolly, slash, and longleaf pine seeds[1]

Species	Hours of absorption	Absorption temperature (°F)				
		48	60	72	84	96
		--Percent--				
Loblolly	8	24	27	27	27	29
	24	29	30	31	32	33
	48	32	32	33	35	33
	72	32	34	34	35	33
	96	33	34	35	35	34
Slash	8	24	27	30	32	33
	24	32	35	38	41	44
	48	39	39	42	47	47
	72	38	40	46	49	47
	96	41	44	48	49	48
Longleaf	8	24	26	28	30	39
	24	32	37	42	48	40
	48	39	50	59	59	44
	72	45	57	66	63	41
	96	52	68	75	68	57

[1] Staggered lines show moisture contents where seedcoats are ruptured and germination begins. Normally this occurs at about 36 percent for loblolly (Barnett 1976), 40 percent for slash, and 55 percent for longleaf pine.

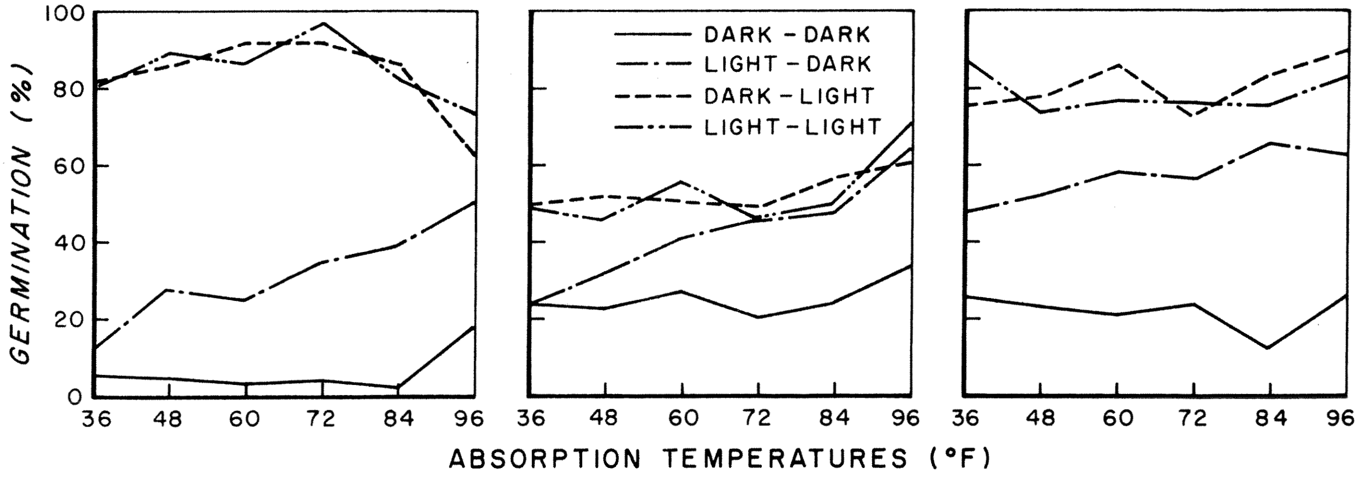

Figure 1.--Germination of single-tree lots of loblolly pine seeds as affected by absorption temperatures and light conditions during absorption and germination.

Table 2.--Germination percentages and values of loblolly, slash, and longleaf pine seeds after varying absorption temperature and light regimes for 48 hours 1/

Temperature	Light condition	Germination Loblolly	 Slash	 Longleaf	Germination value Loblolly	 Slash	 Longleaf
°F		---------Percent---------					
48	Light	92 a	79 a	82 a	17.2 c	23.6 b	25.1 b
	Dark	93 a	82	88	17.5 cd	23.3	30.2
60	Light	94 a	78 a	86 a	20.7 a	26.4 ab	32.8 a
	Dark	96 a	78	86	18.7 b	25.2	31.6
72	Light	94 a	80 a	87 a	18.0 bc	29.6 a	31.0 a
	Dark	86 c	78	87	14.5 f	26.7	34.4
84	Light	92 a	76 a	83 a	16.5 e	26.1 ab	27.4 ab
	Dark	94 a	80	86	17.9 bc	27.3	30.5
96	Light	91 b	70 b	76 b	16.4 de	20.8 c	20.3 c
	Dark	90 b	64	82	15.9 e	18.4	25.4

1/ Species means followed by the same letter are not significantly different at the 0.05 level. Slash and longleaf means were not significantly affected by light conditions, so average values for temperatures were analyzed for these species.

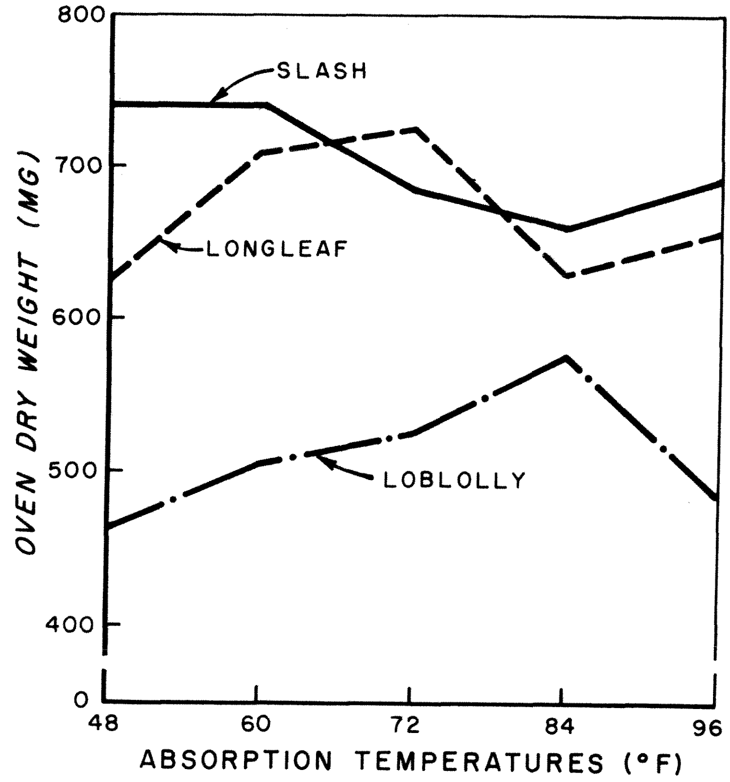

Figure 2.--Dry weights of longleaf, slash, and loblolly pine seedlings grown from seeds with different temperatures of moisture uptake and germinated and grown in light for 12 weeks.

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GROWTH OF EASTERN WHITE PINE SEEDLINGS USING GREENHOUSE CULTURE TECHNIQUES [1]

Ronald L. Hay [2]

Abstract.--White pine seedlings were grown in Hillson-sized rootrainers in the greenhouse for seven months using supplemental light, carbon dioxide, and fertilizer treatments. Biomass and root collar diameter responded positively to extra photoperiod, but height growth was not influenced by light. Height growth was slowed by supplemental carbon dioxide and fertilizer. Root biomass was increased by supplemental carbon dioxide and light. Seedling top biomass was increased by fertlizer topdressings, but this treatment decreased root biomass.

INTRODUCTION

Eastern white pine (Pinus strobus L.) is one of the important native gymnosperms in Tennessee. It is common in the Blue Ridge Mountains of eastern Tennessee, and it is somewhat less abundant in the Cumberland Mountains. Its importance as a source of lumber has long been known locally, and markets have occasionally developed to increase the demand regionally. At one time, the largest eastern white pine in North America was growing in the mountains of East Tennessee.

More recently the demand for white pine lumber, Christmas trees, and ornamental landscaping products has greatly increased the demand for white pine planting stock. Each year for the last several years, the Tennessee Division of Forestry has not had an adequate supply of 2-0 white pine seedlings. Estimates have placed the potential demand far in excess of available seedlings, perhaps by as much as 500 percent. Demand for white pine planting stock has greatly exceeded available supplies in recent years, and there is every reason to believe that the trend will continue.

White pine has some seedling growth characteristics that lengthen its stay in the nursery, thereby increasing the difficulty and cost of high production efficiencies. For example, white pine seedlings do not usually develop secondary leaves during their first growing season. The cotyledons are functional until the epicotyl begins to elongate and the efficient, primary leaves appear. These leaves provide photosynthate during the first growing season. The overwintering buds appear relatively early, usually by mid-summer, and height growth stops. Seedlings are usually much too small to be considered for outplanting after one year in the nursery. During the second year in the nursery, secondary leaves are produced and most seedlings grow to sufficient size to survive outplanting.

Containerized culture of pines in greenhouses has numerous advantages over standard nursery culture techniques, especially for those species that have problems in nurseries. In a greenhouse, environmental problems can be readily controlled, while providing conditions conducive to seedling growth. The greenhouse environment facilitates the efficient use of fertilizers and inoculation of the growing medium with appropriate mycorrhizal symbionts, e.g., both supplemental slow-release fertilizers and fungal symbionts can be added to the growing medium before containers are filled. Subsequent applications of liquid fertilizers can be made during watering. Fertilizer can be formulated to meet specific needs at specific times to best stimulate growth. Timing of greenhouse operations is not dependent upon the weather, therefore with good management, quality seedlings can be ready in quantity for any anticipated outplanting date.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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The objective of this study was to evaluate seedling growth from greenhouse, containerized culture using supplemental photoperiod, carbon dioxide, and fertilizer topdressing treatments to obtain seedlings suitable for outplanting at age eight months. Emphases were placed on seedling size, biomass of tops and roots and morphology of the leaves.

PROCEDURES

Preliminary Study

In May, newly germinated white pine seedlings from the same seed source were transplanted into Hillson-sized rootrainers and grown in three separate environments. One treatment was 70 percent lath shade with natural photoperiod and daily temperature regimes. The other two groups of seedlings were placed in the greenhouse with one treatment receiving enough supplemental light to comprise a daily photoperiod of 18 hours. The third treatment was natural photoperiod within the greenhouse environment. All seedlings were fertilized (23-19-17) at 10-day intervals after they had become established.

At age 7 months, 35 seedlings selected at random from each group were harvested and analyzed for growth and biomass variables. For comparison, 35 seedlings were selected at random from each of 2 nursery treatments at the Pinson Nursery; one group had been spring-seeded with stratified seed and those seedlings were about 8 months old, while the second group of 12 month old seedlings had been fall-seeded relying upon natural temperature and moisture regimes to break seed dormancy. Other than the differing seed schedules, all seedlings at Pinson were grown with standard operational procedures, including shading, watering, fertilizing, and weeding.

Greenhouse Culture Study

Based upon information derived from the preliminary tests, a study was established in the greenhouse during October, 1979, to test the effectiveness of selected culture techniques for growing white pine seedlings that would be suitable for outplanting at 8 months of age or less. Supplemental light, carbon dioxide, and fertilizers were incorporated within the randomized block experimental design.

The study was conducted in two greenhouses, one of which was equipped with a carbon dioxide generator fueled by propane. In the absence of carbon dioxide monitoring equipment sensitive to 300 ppm concentrations, the carbon dioxide generator was operated according to manufactuers suggested levels for 6 hours each night. To maintain acceptable day-time temperatures, the carbon dioxide house was usually vented each morning, thereby negating any effect of supplemental carbon dioxide until the next cycle.

Supplemental light was provided in each house with a bank of six Gro-lux, fluorescent lamps over each bench on a continuous photoperiod. The intention was to provide growth stimulation and not just to retard bud set. As a matter of fact, the light controls, i.e., natural photoperiod treatment, received a one-hour interruption of the dark period with enough light to prevent bud dormancy and maintain active seedling growth.

All seedlings received soluble fertilizer (20-20-20) incorporated with regular waterings on a 10-day interval. Slow-release fertilizer had not been added to the mix previously. In addition, half of the seedlings in each carbon dioxide and light treatment also received a topdressing of 25-10-10 at 20-day intervals.

At seven months of age, the seedlings were harvested. Height, root collar diameter plus biomass of roots and tops were measured and analyzed.

RESULTS

Preliminary study

Seedling sizes were encouraging for growing white pine in containerized, greenhouse culture (table 1). In most cases, the extra light of the 18-hour photoperiod helped produce seedlings at 7 months of age that were the same size or larger than nursery-grown seedlings at 12 months of age. The 8-month old nursery-grown seedlings were clearly the smallest of all seedlings.

Height growth was greater in the 12-month nursery treatment than in the supplemental light treatment. Root collar diameter and biomass were significantly increased by the supplemental light treatment. Biomass estimates were especially noteworthy for the 18-hour photoperiod, for those seedlings were significantly larger than any others and the balance of roots and tops was good.

In addition to those easily measured variables, there were several other important differences. For example, foliage color on the 18-hour photoperiod seedlings was dark, blue-green and healthy. Foliage on the other treatments was yellow-green and some leaves were dying. Most seedlings growing under natural photoperiod had dormant terminal buds, but the 18-hour photoperiod seedlings were still actively growing when they were harvested.

Perhaps the most important difference was the abundance of secondary leaves on the 18-hour photoperiod seedlings. These seedlings started developing secondary leaves from buds at the axils of the primary leaves shortly after they received the extended photoperiod. By the time of harvest, the secondary leaves were fully developed and covered most of the length of the epicotyl with the primary leaves. Considerable photosynthetic surface

Table 1.--Mean sizes of eastern white pine seedlings after growing in rootrainer culture or nursery beds for varying periods.

Treatment	Height	Root Collar Diameter	Biomass Roots	Biomass Tops
	cm	mm	g	g
Greenhouse				
18-hour photoperiod	8.1b[1]	1.7a	0.42	0.50a
natural photoperiod	6.8c	1.4c	0.37	0.33c
Outside-lath shade				
natural photoperiod	7.9b	1.5b	0.38	0.39b
Pinson Nursery				
fall seeding	9.5a	1.6a	none	0.44b
spring seeding	5.3d	1.2d	none	0.27c

[1] Lower case letters refer to those means that were grouped as equal at the 0.05 probability level with Duncan's Multiple Range Test.

area was manifested through this proliferation of of secondary leaf tissue.

Greenhouse Culture Study

Adjusted means for the growth variables are presented in table 2. Height growth was significantly and adversely affected by fertilizer topdressing and carbon dioxide treatments (P>0.01). The tallest seedlings were grown without extra carbon dioxide and without fertilizer topdressings. The extra light, carbon dioxide, and fertilizer topdressing treatments produced the shortest seedlings.

Root collar diameter was statistically greater (P>0.01) for seedlings receiving extra light, but it was statistically the same for all other treatments at seven months. Carbon dioxide had a positive effect, but it was not significant (P>0.05).

Biomass can be an important indication of anticipated outplanting success assuming height and diameter are adequate. The influence of supplemental light was strongly manifested with the biomass variables; fresh and dry weights of tops and roots were highly significant (P>0.01). Neither supplemental carbon dioxide nor fertilizers had any significantly positive effects on fresh

Table 2.--Growth of eastern white pine seedlings using light, carbon dioxide, and fertilization treatments for seven months in a greenhouse.

	Growth Variable						
Treatment	Height	Root Collar Diameter	Top Biomass fresh	Top Biomass dry	Root Biomass fresh	Root Biomass dry	Root/Shoot Ratio
	cm	mm	g	g	g	g	%
Photoperiod							
Continuous	7.3	2.3	2.851	0.843	0.767	0.203	25.4
Natural	7.4	1.7	1.394	0.382	0.347	0.070	19.1
Carbon Dioxide							
Supplemental	7.1	2.0	2.106	0.638	0.633	0.154	25.3
Natural	7.6	1.9	2.138	0.588	0.481	0.124	20.9
Fertilizer							
Base (20-20-20)	7.5	2.0	2.096	0.596	0.617	0.150	24.1
Base plus topdressing (25-10-10)	7.2	2.0	2.148	0.630	0.497	0.128	20.3

or dry weights of seedling tops. The supplemental carbon dioxide treatment significantly (P>0.01) increased root weights. Fertilizer topdressings decreased root fresh and dry weights (P>0.05), while top biomass remained unchanged. The effect was decreased root/shoot balance.

Root/shoot ratio, as calculated from dry weights, showed supplemental light and carbon dioxide to have significant benefits to a well-balanced seedling. In both cases roots were better developed when the seedlings were grown with supplemental carbon dioxide and a continuous photoperiod. Fertilizer topdressings reduced the root/shoot balance through a decrease in root weight and an increase in top weight.

DISCUSSION

The worth of any seedling culture technique may not always be found in growth statistics at the end of the culture period, rather the ultimate test will be the success of the outplanting operation for which the seedlings were grown. However, some good inferences about outplanting success can be gleaned from seedling growth performances during greenhouse culture.

Quality white pine seedlings for outplanting should have enough height and diameter to survive the outplanting operation and still be in a favorable position to grow with the competing vegetation. Enough energy reserves must be present to sustain growth processes while seedling roots become established. The foliage should begin photosynthesis quickly, therefore a good mixture of primary and secondary leaves with healthy color is required. Were seedlings with such characteristics produced in this experiment? Some of the treatments were quite effective, but not all of the answers are available yet.

Light had a positive growth influence beyond the requirement to interrupt the dark period in order to maintain active growth during winter months. Diameter and biomass, both of which reflect the extent that photosynthate production and accumulation results in secondary growth, were significantly enhanced by extra light, either an 18-hour or a continuous photoperiod. Although seedlings were not rapidly elongating tops or roots, the cambium was using photosynthate to thicken the stem and secondary leaves were produced from buds that broke dormancy as a result of the extra light. Perhaps most significantly, the root biomass was increased, indicating storage of carbohydrates and other energy-rich compounds that would keep the seedling growing vigorously during that critical time of field establishment.

The influence of supplemental carbon dioxide was positive for seedling diameter and biomass growth. The appearance of seedlings in the carbon dioxide greenhouse, especially those receiving supplemental light, gave further indication of their suitability for outplanting. They had good foliage color and the secondary leaves were well-developed along the entire stem. Although data analyses did not reveal a light and carbon dioxide interaction, expectations of outplanting success are great for those seedlings receiving both supplemental light and carbon dioxide. Increasing propane costs may negate the reality of growth benefits derived in carbon dioxide enriched atmospheres, however.

Topdressings of 25-10-10 once every 20 days produced positive growth responses to seedling tops and adversely affected root biomass and seedling height growth. Tops were direct recipients of the fertilizer mist and they apparently made immediate use of the nutrients. Translocation of photosynthate into the roots was not a factor as reflected by root biomass. Neither was there elongation of primary tissues. Without separate biomass analyses of leaves and stems, it was impossible to locate the source of biomass accumulation in the seedling tops.

Other questions are yet to be addressed in this greenhouse culture technique. What will be the effects on seedling growth of differing container sizes, differing growing media, slow-release fertilizers, ectomycorrhizal symbionts, and how about higher concentrations of carbon dioxide, different fertilizer formulations and application timing? Obviously we are just getting started.

SPOT SEEDING IS EFFECTIVE AND INEXPENSIVE FOR REFORESTING SMALL ACREAGES[1]

T. E. Campbell[2]

Abstract.--First-year establishment of one or two seedlings on 1,000 spots per acre produced fully stocked stands of slash and loblolly pines on both medium and poor quality sites by age 10. Starting with five and nine seedlings per spot also produced fully stocked stands but resulted in slightly reduced height and diameter growth.

Direct seeding is a successful and widely accepted method of regenerating southern pines. Though broadcast sowing from aircraft is generally used on large areas, spot sowing by hand is an excellent alternative for small tracts or where broadcasting is impractical (Lohrey 1970). Spot seeding requires only 1/3 to 1/2 the seed used in broadcast sowing and permits better control of stocking and spacing than is possible with broadcasting. It is also cheaper, faster, and less laborious than hand planting nursery seedlings. Spot seeding is especially suitable for small landowners who must keep out-of-pocket expenses to a minimum (Mann and Burns 1965). But when multiple seeds are dropped on a spot to insure maximum stocking, several seedlings often result. Such clustering is not a serious problem up to age 3 for species that readily express dominance, but little is known about its effect beyond that age (Campbell 1964).

This study was designed to show how many seedlings are needed per spot to insure adequate stocking and how multiple trees per spot affect growth. Slash (*Pinus elliottii* Engelm. *elliottii*) and loblolly (*P. taeda* L.) pines were established with one, two, five, and nine seedlings per spot on both medium and poor quality sites. This paper reports measurements of the study at 10 years.

METHODS

The four seedling densities were established on 0.1-acre square plots and were replicated four times in a randomized block design for two species on two sites.

The site judged to be of medium quality is a Ruston fine sandy loam; surface soil is brown in color, about 8 inches deep, and overlays a red sandy clay loam subsoil. Surface and internal drainage are good. The poor quality site is on a Cadeville sandy loam; surface soil is gray in color, is about 6 inches deep, and is underlain by a slowly permeable reddish brown clay. Surface drainage is adequate. Scattered second-growth longleaf pines and many scrub hardwoods covered both sites. Before the study was installed pines were removed and hardwoods were injected with herbicides.

Seed spots were prepared at 6.6-ft square spacing (1,000 per acre or 100 per plot)--leaves and duff were scraped away with a fire rake, and mineral soil was exposed. Spots were hand sown with about 20 stratified, repellent-treated seeds to insure heavy stocking on each spot. Seeds were pressed into mineral soil with the seeder's boot. After one complete growing season, spots were thinned to appropriate densities of the tallest seedlings per spot.

The central 36 spots on each treatment plot were measured at age 10. Seedling survival was determined from the difference between total tree counts on all 36 spots at ages 2 and 10. Spot stocking was the proportion of spots stocked with one or more seedlings and trees per spot was the average per stocked spot. Total height and d.b.h. were measured for the tallest tree on each of 36 spots, and for every tree on nine central spots within the 36 measurement spots. Heights were measured to the nearest 1-ft with a telescoping pole and d.b.h. to the nearest 0.1-inch with a diameter tape. For each measurement variable,

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differences between spot densities were tested for significance at the .05 level by analysis of variance. Separate analyses were made for each species on each site. Experimental design did not permit statistical comparison of species or sites.

RESULTS AND DISCUSSION

Survival

Mean survival ranged from 92.5 percent for loblolly single-tree spots on the medium site to 60.7 percent for slash nine-tree spots on the poor site (table 1). On the medium site, single trees of both species survived better than trees on plots with nine per spot. Three single-tree plots on the medium site had 100 percent survival; one was slash pine and the other two were loblolly. On the poor site, seed spot density did not affect survival of either species.

Table 1.--Mean survival from age 2 to 10[1]

Trees per spot after thinning	Slash pine		Loblolly pine	
	Medium site	Poor site	Medium site	Poor site
Number	Percent			
1	89.2a	72.9a	92.5a	78.7a
2	84.7ab	76.5a	76.3bc	89.1a
5	83.7ab	63.8a	86.9ab	88.5a
9	68.6b	60.7a	62.6c	79.2a

[1] By column, treatment means not followed by the same letter are significantly different at the 5-percent level.

Spot Stocking

At age 10 on both sites, slash pine thinned to five and nine trees per spot had higher stocking rates than plots with one or two trees per spot (table 2). The trend was similar, but not so clearcut, for loblolly--the five-tree treatment on a medium site and the nine-tree treatment on a poor site both had better stocking than the one- and two-tree treatments.

These results seem reasonable since spots with more trees growing on a better site had an initial advantage. But single-tree spots provided an excellent stand of 727 (625 to 833) well-spaced 10-year-old trees per acre.

Plots thinned to two seedlings per spot at age 2 still averaged 1.6 and 1.7 trees 8 years later, or 84 percent of original stocking. As expected, survival on denser spots was proportionately less because of greater competition for growing space. Five-tree spots averaged 2.9 to 4.1 ten-year-olds, and nine-tree spots averaged 3.9 to 5.2.

Tree Size

The tallest slash pine per spot on the medium site at the highest density averaged 23 ft. It was significantly shorter than the average tree on one- and two-tree spots, but the difference was only 2 ft (table 3). Single loblolly pines on the poor site averaged 28 ft while the tallest tree on double spots averaged 24 ft, but the difference was probably not caused by the extra tree.

Height differences between the tallest and second tallest trees on multiple-tree spots ranged from 2.1 to 6.8 ft by treatment. These two extremes were both loblolly pines on the medium site; the greatest difference occurred on two-tree spots and the least difference on nine-tree spots. The other 10 combinations of density, species, and site had average differences of only 2.5 to 4.1 ft. Dominants in all combinations of species, site, and multiple trees are probably firmly established, with enough height advantage to maintain their superiority. And as trees age, spot density will probably influence height differences more because growth of suppressed and subordinate trees will slow.

Seed spot density in three of the four species-site combinations significantly influenced d.b.h. Single slash pines on the medium site averaged 4.6 inches, and single loblolly pines on the poor site averaged 4.4 inches. Both were larger than dominant trees on all multiple-tree spots for those treatments (table 3). Also, single and double trees were larger than those on five- and nine-tree spots for loblolly on the medium site. Single trees were up to 1.4 inches larger than dominant trees on five- and nine-tree spots because of clustered competition. The tallest tree on a multiple-tree spot was not always the largest in d.b.h., however. Occasionally, a codominant or intermediate tree had greater d.b.h., but only the tallest trees were being compared.

The tallest and second tallest tree per multiple-tree spot differed significantly in d.b.h. for both species on the medium site--differences were greater for doubles than for five- and nine-tree spots. Neither species had significant differences on the poor site; so trees apparently express dominance more readily on a good site than on a poor site.

RECOMMENDATIONS

Mann and Burns (1965) recommend the small landowner sow six seeds on each of 1,000 prepared spots per acre. But their studies were concerned only with seedling establishment. Ten-year results of this study support their recommendation, based on the well-established rule-of-thumb used in direct seeding that one seedling is obtained from each three seeds sown. Five seeds per spot will, under normal circumstances, establish at least one seedling on most spots while four or five will be a rarity. The overall average will be one to three seedlings per spot.

Starting with 1,000 spots per acre, this study yielded from 625 to 902 spots stocked with one or two trees at age 10. Though spot densities of five or nine seedlings significantly improved the proportion of spots still stocked, an average of 758 well-spaced spots per acre with one or two trees each is an excellent stand. Land managers who prefer fewer stocked spots per acre could sow proportionately fewer spots.

Growth rates were also better with fewer trees per spot. Though spot density had only a small influence on heights of the dominants in a cluster, height growth of one or two trees per spot was slightly better than height growth in more densely stocked stands. Diameter growth of dominants on the less dense spots showed a decided advantage of up to 1.4 inches in 10 years.

Because of these advantages, higher spot densities are undesirable, but not completely unacceptable. Up to nine seedlings per spot yielded higher per-acre spot stocking, survival was adequate, individual tree dominance was established early, and height growth was reduced only minimally. Reduction in diameter growth was greater, but volume-per-acre differences should be made up in the extra stems.

Results from this study show conclusively that spot seeding is a practical alternative to planting nursery seedlings. And it is especially suited to the small-woodlot owner. He can do the job in his spare time, use tools available around the farm such as a fire rake or potato hoe to prepare the spots, and do it with less effort in less time at less cost than planting. Raking a spot to mineral soil and dropping five seeds is far less laborious than opening a slit with a dibble, properly placing the seedling roots, and closing the slit. Sowing a spot requires 25 to 50 percent less time than planting a seedling. And at local 1979 prices, sowing 1,000 spots with five loblolly seeds instead of planting 1,000 seedlings would save $10.40. These savings in effort, time, and money make spot seeding an attractive establishment method for farmers, 4-H Club students, and landowners with small, understocked tracts.

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Table 2.--Stocked spots per acre from 1,000 seeded, and mean trees per stocked spot at age 10

	Stocked spots[1]				Trees per spot			
	Slash pine		Loblolly pine		Slash pine		Loblolly pine	
Trees per spot after thinning	Medium site	Poor site	Medium site	Poor site	Medium site	Poor site	Medium site	Poor site
				Number				
1	792b	625c	833b	660c	1.0	1.0	1.0	1.0
2	902b	729b	764b	757bc	1.7	1.6	1.7	1.7
5	986a	861a	965a	854ab	3.9	2.9	4.1	3.5
9	972a	910a	896ab	909a	5.2	3.9	4.8	5.1

[1] By column, treatment means not followed by the same letter are significantly different at the 5-percent level.

Table 3.--Mean total height and mean d.b.h. of the tallest tree per stocked spot at age 10[1]

	Height				D.b.h.			
	Slash pine		Loblolly pine		Slash pine		Loblolly pine	
Trees per spot after thinning	Medium site	Poor site	Medium site	Poor site	Medium site	Poor site	Medium site	Poor site
Number	Feet				Inches			
1	25a	17a	27a	28a	4.6a	2.8a	4.3a	4.4a
2	25a	19a	28a	24b	4.1b	3.1a	4.1a	3.4b
5	24ab	19a	26a	26ab	3.2c	2.9a	3.3b	3.5b
9	23b	18a	26a	25ab	3.2c	2.7a	3.5b	3.2b

[1] By column, treatment means not followed by the same letter are significantly different at the 5-percent level.

PRESCRIBED BURNING BY AERIAL IGNITION[1]

Dane Roten[2]

Abstract.--The N.C. Division of Forest Resources is utilizing a Mark II aerial ignition dispenser developed by the Pacific Forest Research Center in Victoria, British Columbia, to conduct prescribed burnings. The dispenser is mounted in a UH1B helicopter. The aerial ignition device (AID) is a polystyrene ball containing potassium permanganate. Ignition occurs in 25 to 30 seconds after the AID is injected with an ethylene glycol solution. Average cost for firing for hazard reduction and silvicultural burning is $1.31 per acre and $1.57 for site preparation burning.

The use of aerial ignition in prescribed burning was first developed in Australia during the mid-sixties for hazard reduction purposes. An automated machine mounted in a fix-winged aircraft was used to eject incendiary capsules at a predetermined spacing along parallel flight lines over the area to be burned. An aircraft was capable of safely burning up to 30,000 acres in a single day (Dept. of Forestry, Western Australia).

The N.C. Division of Forest Resources first became aware of aerial ignition burning techniques while hosting an Australian fire study tour during 1971. In 1975, I had the opportunity to participate in a return fire study tour. While we did not see an aerial ignition prescribed burn, the results were very obvious. Hazardous forest fuel accumulation in the commercial eucalypt forest, a condition which often resulted in large destructive fires, had been practically eliminated.

In 1977, the N.C. Division of Forest Resources, in cooperation with Weyerhaeuser Company, borrowed a Mark II aerial ignition dispenser from Premo Plastics located in Victoria, British Columbia, to conduct aerial ignition studies. The results were so impressive that a Mark II dispenser was purchased and installed on a UH1B helicopter. Since the initial purchase, two additional dispensers have been obtained.

The Mark II aerial ignition dispenser was developed by the Pacific Forest Research Center in Victoria, British Columbia. It is manufactured and sold by Premo Plastics Engineering Ltd., 863 Viewfield Road, Victoria, British Columbia. The dispenser has four feed chutes through which aerial ignition devices (AIDs) are dispensed. Each chute is capable of dispensing one AID per second. The chutes may be operated in any combination of one to four. The number of chutes activated and the speed of the helicopter determines the ignition spacing along the flight line. The aerial ignition device (AID) is a high impact polystyrene ball 1.25 inches in diameter. It contains 3.5 grams of potassium permanganate. As the AIDs are dispensed through the chutes, they are automatically injected by a hollow steel needle with 1 ml. of 50% ethylene glycol solution. The chemical reaction normally produces (Sain 1979) ignition in about 25 to 30 seconds.

The objectives of our aerial ignition program are to expand prescribed burning capabilities for hazard reduction, site preparation, and silviculture burnings and to develop techniques for burning-out and backfiring in the control of wildfires.

The procedure most often used in aerial ignition for hazard reduction and silvicultural burning is to fire the base line downwind and allow the fire to back a safe distance. The base line is usually fired by hand; however, it may be

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fired by aerial ignition if readily visible from the helicopter. When the base line is secure, flight lines are flown upwind at a predetermined spacing. This procedure keeps the helicopter out of the smoke and results in a backing fire should a breakdown occur. Other methods of firing may be desirable when the base line is not perpendicular to the wind direction.

Studies conducted by the N.C. Division of Forest Resources indicate that the spacing of spot fires determines the intensity of the burn within certain limits. These observations indicate that close spacing results in a shorter burn-out time with more heat being released per unit of time and consequently resulting in a more intense burn. These observations concur with research done by Sackett which indicated that close spacing (Sackett 1968) produced more intensive burns. Optimum spacing to maximize results and to minimize costs in hazard reduction and silviculture burnings appears to be about two chains by two chains when burning under Division of Forest Resources's guidelines. When stand conditions are such that a more intense burn is required either to eliminate additional fuel in hazard reduction or to kill larger diameter hardwoods for silviculture purposes, the spacing may be reduced. During marginal burning conditions, closer spacing may be used to intensify the burn in stands that otherwise would be difficult to burn under existing weather conditions.

The Mark II dispenser transported by a UH1B helicopter has the capability of firing approximately 1,000 acres per hour when flight lines are spaced one chain apart. Production can be increased by increasing the distance between flight lines.

Firing techniques and ignition spacing may vary considerably in site preparation burning. The various techniques of strip spot firing, perimeter firing, key hole firing, plus the technique of starting in the center and firing outward in increasing circles may all be used successfully. As with hazard reduction firing, the burn-out time can be reduced and the fire intensity increased by reducing the spacing between spot fire ignitions. Very strong convection can be formed in heavy fuels by rapid close spaced firing techniques which produce effects similar to mass ignition.

In an effort to minimize stand damage when burning in an existing stand, we recommend strict adherence to the guidelines established by Sackett. Research done by Sackett indicates that the optimum relative humidity range for a successful burn is 30% to 60% and the optimum wind (Sackett 1968) between one and five miles per hour. A rule-of-thumb for converting open 20 foot standard wind velocities to in-woods velocities is: In closed canopies - 10% of open wind velocity, in open stands such as natural longleaf - 25% of open wind velocity. As a guide, we have used 60°F as an upper temperature limit for winter hazard reduction burning. These guides are conservative when burning in more mature pine stands; however, they are realistic when burning in younger pine plantations.

The N.C. Division of Forest Resources does contract aerial ignition for the forest land of the State. Prices are graduated depending upon the size of the area to be burned. The charges range from $5.00 per acre for tracts less than 30 acres down to $1.50 per acre for tracts over 1,000 acres. These charges cover the cost of AIDs (10¢ each), operating cost of the UH1B helicopter ($130/hr.), and the cost of personnel and equipment required to execute the burn. Additional charges are made for line construction. These charges vary from $75 per mile for plowed lines in existing stands to $190 for bladed lines in site prepared areas. Our average cost for AIDs and helicopter operation for the past year was $1.31 per acre for hazard reduction and silviculture burns and $1.57 per acre for site preparation burns.

Last year we burned 12,148 acres for hazard reduction, silvicultural purposes and wildlife habitat improvement, and 5,873 acres for site preparation for a total of 18,021 acres. We have a need to burn 200,000 acres annually for hazard reduction and silviculture purposes. While we do not anticipate ever having the capability to completely fulfill this need, we do hope to develop private contractors capable of providing this service to the large industrial landowners.

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TIMBER AND WILDLIFE IMPLICATIONS OF FIRE IN YOUNG UPLAND HARDWOODS[1]

Jimmy C. Huntley and Charles E. McGee[2]

Abstract.--Upland hardwood stands on good sites were burned after clearcutting to determine the effects of fire on species density, frequency, composition, and dominance. One fire in 4- to 6-year-old stands did not substantially alter a trend whereby oak was replaced by other species. The stands recovered rapidly from the fires and loss of growth and stem quality appeared to be small. Increased browse density and herbaceous coverage improved wildlife habitat.

A particularly vexing problem in upland hardwood management has been the inability to adequately regenerate oak on good sites. Recognizing this problem, the 1979 John S. Wright Forestry Conference at Purdue University was entitled "Regenerating oaks in upland hardwood forests." In a recent research evaluation the Hardwood Research Council described the regeneration of oak problem as "most urgent" (McLintock 1979).

A decline of oak on good sites will have a substantial impact on timber production through the loss of high quality oak veneer and sawlogs. On poorer sites--where oak seems to regenerate readily--timber is often poor quality and suitable only for low-value products.

The greatest impact of oak loss may be upon wildlife because oak is an important food source for many species. Van Dersal (1940) reported that 186 different kinds of wildlife feed on oak, and that acorns were a preferred or staple food for a great number. Hamilton (1941) reported that deer mice, white-footed mice, and red-backed voles often ate large quantities of mast, particularly beechnut and acorns. (Scientific and common names of all species are included in the appendix.) From an intensive review of food habit studies, Martin, Zin, and Nelson (1951) drew the following conclusions: In the Southeast, oak ranked first in percentage of use by wildlife and only Panicum spp. and corn were used by more species. In the eastern United States, oak comprised over 25 percent of the diet of wood duck, wild turkey, blue jay, black bear, raccoon, lesser prairie chicken, eastern fox squirrel, gray squirrel, and white-tailed deer. Oak comprised over 5 percent of the diet of ruffed grouse, bobwhite quail, common grackle, white-breasted nuthatch, brown thrasher, tufted titmouse, rufous-sided towhee, red-bellied woodpecker, red-headed woodpecker, flying squirrel, eastern chipmunk, and white footed mouse.

Recent studies have documented the loss of oak from good hardwood sites. McGee and Hooper (1970, 1975) found that a stand of high quality mixed hardwoods in the southern Appalachians, which had been mostly oak with prolific advance reproduction, converted quickly to yellow-poplar following clearcutting. In a summary of research in the central Appalachians, Trimble (1973) and Smith (1979) concluded that neither selection-cutting nor clearcutting adequately regenerated oak on excellent sites (site index 80). Yellow-poplar was a major component of regeneration on such sites. They found that on fair oak sites (site index 60), clearcutting regenerated oak better than selection-cutting. Merz and Boyce (1958) found in southern Ohio that cutting intensity may have a greater impact on oak regeneration than site quality. However, the general trend on good sites has been the loss of oak after either selection-cutting or clearcutting.

Recent hardwood management guidelines suggest that the perpetuation of oak in new stands probably depends on the presence of sufficient

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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advance reproduction in the harvested stand (Roach and Gingrich 1968, Trimble 1973, Sander 1977). Stump sprouts should be considered a supplement to advance reproduction. Merritt (1979) considered lack of advance reproduction a major problem throughout most of the oak-hickory range. But he pointed out that there aren't enough answers to oak regeneration problems. Although the shelterwood system seems theoretically ideal for increasing oak reproduction, research with shelterwood cuttings has been disappointing (Sander 1979).

If the various cutting methods don't enable oak to regenerate adequately, then the question arises: How did present oak stands become established? McGee (1979) points out that today's environment is different from 50 or 100 years ago. The passing of American chestnut and widespread forest fires were suggested as factors that may have affected the establishment of oak stands.

Loss of American chestnut probably had an effect similar to timber harvesting. Depending on the dominance and distribution of chestnut in the stand, different types of cutting would have been simulated. Since different cutting practices have not improved oak regeneration, the role of fire in the origin of oak stands seem worthy of consideration.

Garren (1943), in a review of fire effects on southeastern vegetation said fire was of major ecological importance. In some parts of the region, fire seems to exert as much influence as climate and soil in determining the dominant type of vegetation. The role of fire in maintaining many conifer forest types in the eastern United States has been long recognized (Little and Moore 1949). There is much speculation but little evidence of fire's role in the establishment of oak stands (Merritt 1979, Sander 1977). Stephens and Waggoner (1980) think that dominance of oak in Connecticut is likely the result of both fire and repeated clearcutting for fuelwood and charcoal production, as well as the loss of chestnut.

The need to determine if fire actually played a major role in establishing oak on good sites led to this study. It reports on the effects of burning young upland hardwood stands that had developed after clearcutting. The study's broad objective is to determine if fire affects the species composition and dominance of young hardwood stands. A specific interest is to determine if single burns applied at different seasons increase oak reproduction on good sites. The effect of fire on yellow-poplar is of particular interest since yellow-poplar is often a major competitor to oak on good sites in the southern Appalachian Mountain and Plateau regions.

This exploratory study lacks replication and is limited to a comparison of stand development on two areas burned in the spring, one area burned in the fall, and one unburned area. The aim is to formulate rather than test hypotheses concerning the role of fire in hardwood regeneration. Valuable basic data are provided on fire effects in young hardwood stands in a region where such data were lacking. Information gained can form the basis for future, more intensive research. Earlier reported results (McGee 1979, 1980) emphasized timber-related values while this report considers both timber and wildlife implications.

LOCATION AND DESCRIPTION OF STUDY AREA

In cooperation with Alabama National Forest personnel, four study areas were established in northern Alabama on the William B. Bankhead National Forest. All areas are at least 2 ha (5 acres) and are on slopes between the sandstone top of the Cumberland Plateau and limestone valleys to the north. Elevation relief is about 105 m (350 ft.), ranging from 300 m (1,000 ft.) on top of the plateau to 195 m (650 ft.) in the valleys. Soils lie mostly over limestone but are stongly influenced by sandstone and shale colluvium from the plateau top.

Areas 1, 2, and 3 are within the same stand and are contiguous. Aspect ranges from east to northeast in area 3, northeast to north in area 1, and north to west in area 2. Areas 1 and 3 are adjacent and quite similar except area 3 is farther upslope. Both are good hardwood sites where more mesic species might compete heavily with oaks. Area 2 is a slightly poorer site due to warmer aspect and less protection from surrounding terrain. Oaks were expected to compete well with other species on this site. Area 4 is 19.3 km (12 miles) east of the other three areas. Area 4 is on a north facing slope above a branch of Indian Creek. The creek has eroded through the sandstone cap of the plateau top and formed steep bluffs to the north and east. As a result this area, especially the mid and lower slope, is well protected and the most mesic of all areas. Area 4 is similar to areas 1 and 3.

Prior to harvest each area supported sawtimber stands of mixed hardwoods. The stands were predominately oak with scattered yellow-poplar, white ash, hickory, and other species. The timber was good with numerous individual stems of high quality.

METHODS

Treatments

Harvest and site preparation followed prescribed national forest techniques. Merchantable timber in areas 1, 2, and 3 was harvested in autumn 1970, and all remaining stems 2.54 cm (1 in.) dbh and greater were injected with undiluted 2,4-D in autumn 1971. In area 4 timber was harvested in autumn 1973, and site similarly prepared in autumn 1975.

Area 1 was burned in April 1976, five growing seasons after harvest and four growing seasons after injection. Area 2 was burned in November 1976, six growing seasons after harvest and five growing seasons after injection. Area 4 was burned in March 1978, four growing seasons after harvest and two growing seasons after injection. Area 3 was not burned.

Fire intensity varied between and within all burns. The burn on area 1 was a strip head fire that was generally light and spotty. Twenty percent of the area was virtually burn-free and an additional 36 percent received a light burn with only the top loose layer of litter consumed. The fire was light due to high fuel moisture and partial greenup. As a result of low intensity and coverage many stems were not top-killed.

The burn on area 2 was also a strip head fire but coverage was good and intensity moderate with loose litter and other fine fuels consumed. All reproduction, except the largest, was top-killed. Area 4 was burned with a ring head fire. Coverage was excellent, the fire was intense, and all stems were top-killed.

Data Collection

Density and composition of all woody taxa, except lowbush blueberries and woody vines, were checked with a grid of permanent sampling points. Points were spaced 15 m (50 ft.) apart with two circular nested quadrats at each point. Woody stems greater than 1.4 m (4.5 ft.) in height were sampled with 40.5 m^2 (.01 acre) quadrats, and smaller stems were sampled with 4 m^2 (.001 acre) quadrats which, respectively, gives a 20 percent and 2 percent sampling intensity. Individual stems were recorded by species or in the case of hickory, elm, sumac, azalea, hawthorn, and plum by genera.

Initial inventories were made on all four areas prior to burning. Followup inventories were made yearly after each growing season. Because of different harvesting and burning dates, the number of years of data collection from each study area varies (table 1). Data through the 1979 growing season are included in this report.

Additional data were collected in 1979 to determine height and dominance of woody stems and coverage by herbaceous and vine species. Height and dominance was sampled by dividing each 40.5 m^2 density quadrat into quadrants and recording the species and height of the tallest woody stem in each quadrant. Therefore, 400 dominant stems were tallied for each .4 ha (1 a) sampled area.

Coverage by herbaceous species and woody vines was visually estimated on 1 m^2 (10.8 ft.^{2}) circular quadrats. One quadrat was located 1.5 m (5 ft.) to the right of each permanent sampling point. Field data were recorded by species or genera, but several taxa were grouped into various vegetative categories for data analysis.

Table 1.--Sequence of treatments and inventories on four areas used to study the effect of burning young hardwood stands on the southern Cumberland Plateau, William B. Bankhead National Forest, Alabama

Treatments and Inventories								
Area Number	Harvest	Injection	Initial Inventory	Burned	Re-inventories[2]			
					1 yr.	2 yr.	3 yr.	4 yr.
1	Fall 1970	Fall 1971	Feb. 1976 (5)[1]	April 9, 1976 (5)[1]	Sept. 1976	Oct. 1977	Nov. 1978	Sept. 1979
2	Fall 1970	Fall 1971	Feb. 1976 (5)	Nov. 7, 1976 (6)	Oct. 1977	Nov. 1978	Oct. 1979	
3	Fall 1970	Fall 1971	March 1976 (5)	Not Burned	No Data	Oct. 1977	Nov. 1978	Sept. 1979
4	Fall 1973	Fall 1975	Oct. 1977 (4)	March 20, 1978 (4)	Nov. 1978	Sept. 1979		

[1] Numbers in parenthesis are age of stand in years.

[2] Re-inventories are referenced by the number of growing seasons since burning for areas 1, 2, and 4 and growing seasons since initial inventory for unburned area 3.

RESULTS

Density and Species Composition of Woody Stems

The densities reported below will be the number of stems per 0.4 ha (1 a). Reporting woody data in 2 size classes facilitates an understanding of stand structure.

Small Stems

On unburned area 3 the density of small stems ($\leq$ 1.4 m in height) began decreasing after age 5, when the initial inventory was conducted. Two years after initial inventory density had decreased to 7,623 from 11,249. Although density increased to 13,749 four years after initial inventory, the increase was due to many very small seedlings, primarily red maple. Few of these were expected to survive. On all burned areas the density increased substantially the first year after burning and then generally began a decrease toward preburn levels. The initial increases were from 7,790 to 23,771 on area 1; 11,867 to 36,785 on area 2; and 18,749 to 31,234 on area 4. The increases were due primarily to sprouting from topkilled stems. After 1 year the number of sprouts on all areas began to decrease. But density on area 1, similar to area 3, was increased by the presence of many red maple seedlings. These two areas are contiguous with a red maple seed source in the surrounding forest and from a few residuals not killed during site preparation.

Although major shifts in species composition did not appear after burning, some changes were apparent. Despite being topkilled by fire, all hardwood species sprouted to some degree. However, a common characteristic of oaks on all areas was that northern red oak--the most preferred oak species--did not sprout as well as black, scarlet, white, or chestnut oak. Red maple sprouted vigorously and increased in relative importance on all areas. Yellow-poplar reacted differently between the areas. Immediately following the fires yellow-poplar increased on area 1 but decreased on areas 2 and 4. On area 4, where the fire was hot and reproduction smaller, many yellow-poplar were killed. Yellow-poplar density was very low on area 2 before the fire and almost nonexistent 3 years later. The greatest change on the unburned area was a large decrease in yellow-poplar. Density of small oaks also decreased. Since all stems that become a member of the overstory in the final stand must grow into the larger size class (greater than 1.4 m), a more detailed discussion of density and composition change is presented in that section of the report.

Smaller size stems were most available as browse for white-tailed deer. Not only was browse quantity increased, browse quality was also improved (Blair et al. 1980). Some of the more desirable browse such as red maple, blackgum, dogwood, white oak, and smooth hydrangea had the highest density increase. The increase was persistent and was 211, 171, and 67 percent greater, respectively, than pre-burning densities on area 1 four years after burning, on area 2 three years after burning, and on area 4 two years after burning. The initial percentage increase on area 4 was smaller because it was younger when burned.

Large Stems

Absolute Density.--Unburned area 3 is a good example of how a young stand of hardwoods will develop following silvicultural clearcutting. Density of large stems (greater than 1.4 m in height) reached a peak of 5,140 per 0.4 ha at age 7. Due to ingrowth from the smaller category, oak, yellow-poplar, red maple, hickory, and elm increased in density since the initial inventory at age 5. Black cherry and white ash increased very little. As expected, density of large stems decreased markedly the first year after burning.

The smallest percentage decrease was in area 1 where many large stems were not topkilled by the less intense fire. Stem density on all burned areas is now greater than preburn levels. For areas 1, 2, and 4, respectively, 4, 3, and 2 growing seasons after burning, large stem densities are 5,335; 4,717; and 5,822.

Relative Density.--Changes in species composition as stands age or as a result of a disturbance such as fire are more evident when comparing relative density than absolute density. Relative density presents density on a percentage basis rather than as actual number of stems (table 2). When comparing changes in relative density on the unburned area since initial inventory, the most apparent feature is the stability of species composition. From age 5 to age 9 if individual oak species are excluded, yellow-poplar had the greatest loss--from 17.7 percent to 14.7 percent. Red maple had the greatest increase--from 11.7 percent to 13.7 percent. Although oak totals changed little, differences within the oak group were evident. Northern red oak decreased substantially while black oak, scarlet oak, and white oak increased at just about the same rate.

There were some changes in relative density between preburn and postburn populations. The greatest changes after 4 years on area 1 was a decrease in yellow-poplar from 22.6 percent to 14.1 percent and an increase in red maple from 1.8 percent to 12.1 percent. On area 2, all major species decreased except chestnut oak and red maple. The major increase, from 17.5 percent to 31.0 percent 3 years after the burn, was in the miscellaneous hardwood category. Eighty percent of the stems in this category were small tree and shrubby species. On both areas 1 and 2, the relative

Table 2.--Relative density of woody stems greater than 1.4 m (4.5 ft.) in height at various ages of one unburned and three burned regeneration areas of upland hardwoods on the southern Cumberland Plateau, Bankhead National Forest, Alabama[1]

Area and Year of Inventory[2]	Species[3]													
	All Oaks	NRO	BO	WO	CO	YP	BC	WA	HIC	RM	Elm	BG	DW	Misc. Hdws.
	- - - - - -	- - - -	- - - -	- - - -	- - - -	- - - -	Percent	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -
AREA 3 (Unburned)														
Initial	21.8	8.0	0.8	6.9	6.2	17.7	3.5	3.0	3.3	11.7	5.3	9.8	7.7	16.2
2 Years	20.1	4.4	3.7	6.2	5.8	14.4	3.0	2.7	2.9	13.5	5.1	9.1	10.5	18.8
4 Years	21.0	3.8	3.7	8.4	5.2	14.7	2.6	2.6	3.8	13.7	6.3	9.8	10.9	14.6
AREA 1														
Pre-burn	14.8	7.2	2.0	2.3	3.2	22.6	5.6	6.6	1.9	1.8	2.8	7.6	15.3	21.1
Burned Spring 1976														
1 Year	7.6	3.1	1.3	0.6	2.6	15.8	7.3	9.8	1.0	11.3	2.1	5.3	15.8	23.9
2 Years	8.9	3.8	1.2	1.0	2.9	14.1	7.0	8.7	0.9	12.5	1.6	5.2	14.0	27.1
4 Years	12.2	3.6	2.7	2.6	3.3	14.1	5.2	7.8	2.1	12.1	2.4	6.2	15.1	23.0
AREA 2														
Pre-burn	19.2	5.5	4.6	6.2	2.9	3.2	9.1	5.1	2.0	17.3	9.3	6.7	9.1	17.5
Burned Fall 1976														
1 Year	8.7	0.4	3.2	1.6	3.5	3.3	14.1	8.9	1.6	16.5	5.6	3.5	7.1	29.6
3 Years	14.4	1.3	3.3	5.0	4.8	1.2	8.0	4.8	1.9	19.2	5.3	5.8	8.1	31.0
AREA 4														
Pre-burn	6.8	1.8	0.2	0.9	3.9	6.7	2.3	1.5	2.4	10.5	0.7	2.8	9.1	55.3
Burned Spring 1978														
1 Year	10.8	2.6	1.2	0.8	6.3	8.4	5.7	2.6	1.0	9.0	0.4	5.6	2.8	53.1
2 Years	7.3	2.2	0.8	1.1	3.2	5.1	3.2	1.9	2.8	10.5	0.6	6.0	6.9	55.4

[1] Relative density = $\frac{\text{Density per species}}{\text{Total density}} \times 100$

[2] Years indicate the number of growing seasons since initial inventory on area 3 and since burning on the other areas; areas 1, 2, and 3 were 5 years old at first inventory and area 4 was 4 years old.

[3] NRO--northern red oak; BO--black oak, scarlet oak, southern red oak; WO--white oak; CO--chestnut oak; YP--yellow-poplar; BC--black cherry; WA--white ash; HIC--hickories; RM--red maple; Elm--elms; BG--blackgum; DW--dogwood; Misc. Hdws.--other trees plus shrubby species.

density of northern red oak was substantially reduced after burning. On area 4 the failure of one fire to alter species composition was most apparent. Only 2 years after burning the relative density of all species except blackgum was very similar to preburn levels.

In area 4 the percentage of miscellaneous hardwoods was very high. Sugar maple, American beech, black walnut, and cucumber tree, species characteristic of a mixed mesophytic forest, were present on this area but absent from the other areas. The major difference was that 2 species, eastern hophornbean and carolina buckthorn, were much more abundant on area 4. Eastern hophornbean comprised 20.5 percent of the total stand and was the most abundant single species. As age increases small tree species will be less able to dominate the stands.

Frequency

Frequency to indicate distribution of the various species is presented only for the large stems higher than 1.4 m (table 3). Burning generally had little long term effect on species distribution whether comparing preburn with postburn inventories or burned areas with the unburned area. An exception was an increase in red maple on area 1, which went from 15 percent before burning to 91 percent 4 years after burning. The red maple increase on the other areas was much smaller. Frequency of black oak and hickories increased with time on all areas. The largest decrease in frequency, 18 percent, occurred to northern red oak on area 2.

Table 3.--Frequency of woody stems greater than 1.4 m (4.5 ft.) in height at various ages of 1 unburned and 3 burned regeneration areas of upland hardwoods on the southern Cumberland Plateau, Bankhead National Forest, Alabama[1]

Area and Year of Inventory[2]	Species[3]													
	All Oaks	NRO	BO	WO	CO	YP	BC	WA	HIC	RM	Elm	BG	DW	Misc. Hdws.
	- - - - - - - - - - - - - - - - Percent - - - - - - - - - - - - - - - -													
AREA 3 (Unburned)														
Initial	90	71	23	62	58	83	71	50	46	85	40	79	92	98
2 Years	89	67	60	56	62	90	71	56	56	96	42	75	94	83
4 Years	92	71	60	56	64	83	69	56	62	96	48	83	88	88
AREA 1														
Pre-burn	89	74	38	42	42	88	86	59	44	15	48	77	97	97
Burned Spring 1976														
1 Year	70	44	30	17	41	80	79	59	24	73	30	56	82	79
2 Years	82	64	30	23	47	86	82	59	29	80	35	58	89	95
4 Years	91	73	59	41	56	88	82	62	54	91	45	76	95	97
AREA 2														
Pre-burn	88	57	52	54	21	46	84	62	36	87	67	74	77	92
Burned Fall 1976														
1 Year	57	5	28	16	18	21	62	43	15	56	36	34	44	80
3 Years	90	39	69	64	38	36	92	62	62	92	74	80	87	100
AREA 4														
Pre-burn	62	39	9	17	33	76	45	34	42	78	11	44	88	100
Burned Fall 1978														
1 Year	52	22	17	6	22	39	44	22	6	58	6	36	36	94
2 Years	76	39	30	22	33	69	58	41	56	81	17	70	78	98

1/ $\text{Frequency} = \dfrac{\text{Number of sample plots where species are present}}{\text{Total number of sample plots}} \times 100$

2/ Years indicate the number of growing seasons since initial inventory on area 3 and since burning on the other areas; areas 1, 2, and 3 were 5 years old at first inventory, and area 4 was 4 years old.

3/ NRO--northern red oak; BO--black oak, scarlet oak, southern red oak; WO--white oak; CO--chestnut oak; YP--yellow-poplar; BC--black cherry; WA--white ash; HIC--hickories; RM--red maple; Elm--elms; BG--blackgum; DW--dogwood; Misc. Hdws.--miscellaneous hardwoods including other trees plus shrubby species.

Dominance and Height Growth

Dominance based on tree height is probably the best key to future stand development because trees in superior positions are most likely to compete successfully for nutrients, water, and light.

Dominance information is supplied on a relative basis by calculating the percentage of the total dominant stems that was composed of the same species or species group (table 4). At age 9, oaks, yellow-poplar, red maple, black cherry, and white ash comprised 76 percent of the dominant stems on unburned area 3. On the burned areas, the above species increased in relation to elasped time since burning. On area 4, two years since burning; area 2, three years since burning; and area 1, four years since burning; their respective combined relative dominance is 46, 59, and 77 percent. As time since burning increases and shrubs and small tree species are relegated to the understory, the dominance of this group of species on areas 2 and 4 should increase. But as stand age increases further, we expect a decrease in the vigor of black cherry, white ash, and red maple. If this is true, then yellow-poplar will be the greatest competitor against oaks for space in the ultimate overstory. The effect of burning on the dominance of oaks over yellow-poplar is mixed. Oaks and yellow-poplar are nearly equal on area 4, very similar to unburned area 3. But on area 1, yellow-poplar is much more dominant and on area 2 the reverse is true. Differences in site quality, fire intensity, and stand age at time of burning may account for much of the variability.

Growth since burning has been exceptional on all areas. Average heights of dominant stems in area 1 four years after burning are almost equal to the 9-year-old unburned stand (table 4). However, many stems were not killed, so some dominant stems in area 1 were also 9 year old. On area 4 where all stems were topkilled, the 2-year-old

Table 4.--Relative dominance (RD) and average height in feet of the tallest woody stems on 3 burned and 1 unburned regeneration stands of upland hardwood on the southern Cumberland Plateau, Bankhead National Forest, Alabama (Fall 1979)[1]

Species	Area 3[2] Unburned		Area 1 Burned Spring 1976		Area 2 Burned Fall 1976		Area 4 Burned Spring 1978	
	RD	Avg. Ht.	RD	Avg. Ht.	RD	Avg. Ht.	RD	Avg. Ht.
	%	Ft.	%	Ft.	%	Ft.	%	Ft.
Oaks	19	25	9	22	18	16	10	9
Yellow-poplar	24	28	30	23	5	15	12	11
Red Maple	14	25	7	24	12	15	9	9
Black Cherry	13	28	15	25	15	20	11	10
White Ash	6	24	16	18	9	16	4	9
Dogwood	6	19	8	16	5	16	4	9
Blackgum	3	19	3	18	8	13	6	8
E. Hophornbean	0	--	0	--	1	10	18	9
E. Redbud	7	21	2	17	4	12	2	8
Sweetgum	0	--	1	26	8	20	1	11
Sassafras	0	--	3	17	0	--	4	10
Sumac	0	--	1	14	5	11	1	10
Others	8	--	5	--	10	--	18	--
Total	100		100		100		100	

[1] Dominance was determined by the tallest stem present on systematically located 10 m^2 (109 $ft.^2$) plots. Relative dominance =

$$\frac{\text{Number of plots on which a certain species is tallest}}{\text{Total number of plots}} \times 100$$

[2] Areas 3, 1, and 2 were harvested in fall 1970, site prepared in fall 1971; area 4 was harvested fall 1973, site prepared fall 1975.

dominant stems of major tree species average 3.1 m (10 ft.) in height.

Herbaceous Coverage

Herbaceous species or genera plus woody vines and Rubus spp. were grouped into various categories based on importance to wildlife (table 5). The value of prescribed burning to wildlife is apparent when total coverage between areas is compared. Herbaceous cover decreases as time since the fire increases, from 48.4 percent on a 2-year-old burn to 24.2 percent on a 4-year-old burn, and is lowest at 10.0 percent on the unburned 9-year-old stand.

Legumes, an important source of food for some game species, were scarce on all areas except areas 2 and 4. Wildlife food grasses and sedges, primarily Panicum spp. and Carex spp., were relatively abundant on the most recently burned areas, 2 and 4. Panicum grasses are heavily used by both game and nongame species in the southern United States. Rubus spp., blackberry and dewberry, another heavily used genera were abundant only on area 4. Vine coverage on the burned areas was double that of the unburned area. The vine category contains many species favored by white-tailed deer. The most abundant was poison-ivy but Alabama supplejack, green brier, and grape were also abundant. Only traces of forbs of high value to bobwhite quail were present.

DISCUSSION AND SUMMARY

This study was undertaken to supply information on the effects of fire on young stands of upland hardwoods. A primary interest was to determine if a single fire would increase the importance of oak in young stands. The 4 study areas observed had supported good quality stands --predominately oak--prior to clearcutting. Following clearcutting, some oak was obviously being replaced by faster growing species. The 9-year-old unburned stand (area 3) is indicative of how upland hardwood stands on good sites in the southern Appalachian plateaus will develop following clearcutting. The dominant stand contains yellow-poplar, oak, red maple, black cherry, eastern redbud, white ash, and flowering dogwood in that order. The original oak stand has been converted into a mixed stand where oak is still important but not predominant.

One fire in these young hardwood stands did not appreciably reverse the loss of oak or change

Table 5.--Percent coverage by herbaceous vegetation on burned and unburned regeneration areas of upland hardwoods on the southern Cumberland Plateau, Bankhead National Forest, Alabama (fall 1979)

Vegetative Category	Area 1[1] Burned Spring 1976	Area 2 Burned Fall 1976	Area 4 Burned Spring 1978	Area 3 Not Burned
	Percent			
Legumes	T[4]	3.4	2.0	T
Wildlife Food Grasses & Sedges	3.0	12.6	9.8	1.0
Other Grasses	T	2.4	2.4	T
Vines[2]	14.6	10.6	13.5	6.2
Rubus spp.[3]	2.0	1.6	19.0	T
Composites	2.0	2.4	1.0	1.0
Quail Food Forbs	T	T	T	T
Other Forbs	2.1	1.3	1.0	1.0
Total Coverage	24.1	34.4	48.4	10.0

[1] Areas 1, 2, and 3 were harvested in fall 1970 and site prepared in fall 1971; area 4 was harvested in fall 1973 and site prepared in fall 1975.

[2] Also includes woody vines.

[3] Blackberry and dewberry.

[4] T = trace (less than 1 percent).

species composition. However, the fires had large short term effects on stem density and stand structure, a favorable impact on wildlife habitat, and some effect on species composition. Density of stems less than 1.4 m in height increased substantially after burning because of multiple sprouting from topkilled stems. On area 1, burned 4 years earlier, density per 0.4 ha is now 24,198 as compared with 7,790 before burning. Density of stems taller than 1.4 m was reduced the first year after burning. However, because of rapid sprout growth, density 2 years after burning approached or surpassed pre-burning density on all 3 burned areas.

Some changes in species composition occurred because some stems were only topkilled and sprouted while other stems were completely killed. The hot fire in the 4-year-old stand on area 4 completely killed a number of small yellow-poplar stems. Most of the stems killed were 1- and 2-year-old seedlings that had not developed a large root system. Although many small yellow-poplar stems were killed, most of the larger stems; greater than 1.4 m in height; sprouted, grew rapidly, and maintained their relative importance in the stand. Since yellow-poplar is a major competitor against oak on good sites, burning young stands at the proper age and interval to control yellow-poplar may increase dominance of oak in the ultimate stand.

Red maple was the species that responded most favorably to fire. Small-stem density increased greatly on all burned areas. Although large-stem density increased on all areas, the relative increase was large, from 1.8 to 12.1 percent, only on area 1 which burned with a cool fire. Red maple is a major component of all 4 stands with moderately high density and dominance.

Although a single burning did not seem to greatly favor the development of oak, there were other positive wildlife benefits. The amount of browse available to white-tailed deer was greatly increased, and the increase was persistent 4 years after burning. Burning increased herbaceous growth that contained many important wildlife food plants. Herbaceous coverage ranged from 48.4 percent on a 2-year-old burn to only 10.0 percent on the unburned 9-year-old stand.

Since species composition was only slightly affected, the greatest negative impact of fire would be loss of growth and possible lowering of stem quality. The loss in growth was not as great as anticipated because of rapid sprout growth after burning. Average annual growth of the tallest stems of the major tree species was 1.5 m (4.8 ft.) in the 2-year-old burned area and 0.9 m (2.9 ft.) in the 9-year-old unburned area.

The damaging effect of fire upon hardwood stem quality is well known, and fire scars often serve as entry points for wood decaying organisms (Hepting 1935, Toole 1960). But the damaging effect on young stems that are topkilled may be small. Roth and Sleeth (1939) in a study of oak stands in the Allegheny, Appalachian, and central states found that sprout stands following severe burns had a lower decay incident than those resulting from cutting operations without fire. The plots with the lowest decay had been burned either shortly before or after cutting. They believed that fire reduced decay by lowering the origin of sprouts to or below ground level. Smith (1979) and Watt (1979) also concluded that decay should not be a significant problem in sprout origin reproduction. On area 1 where many stems were not topkilled, fire scaring is quite evident, although many of the smaller wounds have healed with callus growth. Jensen (1969) presents evidence that supports the hypothesis that a wound must remain open to maintain active decay. Shigo (1979) explains how trees, by the process of compartmentalization, restrict to small areas the defects that occur after wounding. Fire may also lower quality by increasing the incidence of multistemmed trees.

In summary, several conclusions can be drawn from our data. An oak component will be present in the developing stands but will be less than that in the original stands. On good sites yellow-poplar will be more abundant in the new stands than in the original ones. A single prescribed burn has a large initial effect on stand density and structure although long term effects appear small. Changes in species composition after burning are small, and oak is not apparently favored to any great extent. At this time many species are present in sufficient density to dominate the ultimate stand. At what age and size the various species will lose vigor and become less important in the stand can be determined only in time. Various wildlife species are benefitted by burning due to the increase in woody and herbaceous growth. The greatest detrimental impacts of burning are loss of growth and possible lowering of stand quality. When stands are burned at a young age and complete topkill occurs, the loss of growth and quality will be minimal.

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APPENDIX I

Scientific and Common Name of Woody Species[1]

Scientific Name	Common Name
Acer rubrum L.	red maple
Acer saccharum Marsh.	sugar maple
Carya spp.	hickory
Cercis canadensis L.	eastern redbud
Cornus florida L.	flowering dogwood
Crataegus spp.	hawthorn
Fagus grandifolia Ehrh.	American beech
Fraxinus americana L.	white ash
Hydrangea arborensens L.	smooth hydrangea
Juglans nigra L.	black walnut
Liriodendron tulipifera L.	yellow-poplar
Magnolia acuminata L.	cucumbertree
Nyssa sylvatica Marsh.	blackgum
Ostrya virginiana (Mill.) K. Koch	eastern hophornbean
Prunus serotina Ehrh.	black cherry
Prunus spp.	plum
Quercus alba L.	white oak
Quercus coccinea Muenchh.	scarlet oak
Quercus falcata Michx.	southern red oak
Quercus prinus L.	chestnut oak
Quercus rubra L.	northern red oak
Quercus velutina L.	black oak
Rhamnus caroliniana Walt.	Carolina buckthorn
Rhododendron nudiflorum (L.) Torr.	pink azalea
Rhus spp.	sumac
Ulmus spp.	elm

Herbaceous and Vine Species

Berchemia scandens (Hill) K. Koch	Alabama supple-jack
Carex spp.	sedge, carex
Panicum spp.	panicum
Rhus radicans L.	poison ivy
Rubus spp.	blackberry and dewberry
Smilax spp.	greenbrier
Vitis spp.	grape
Zea mays L.	corn

APPENDIX II

Common and Scientific Names of Animal Species[2]

Common Name	Scientific Name
	Birds
Blue jay	*Cyanocitta cristata*
Bobwhite quail	*Colinus virginianus*
Brown thrasher	*Toxostoma rufum*
Common grackle	*Quiscalus quiscula*
Lesser prairie chicken	*Tympanuchus pallidicinctus*
Red-bellied woodpecker	*Centurus carolinus*
Red-headed woodpecker	*Melanerpes erythrocephalus*
Ruffed grouse	*Bonasa umbellus*
Rufous-sided towhee	*Pipilo erythrophthalmus*
Tuften titmouse	*Parus bicolor*
White-breasted nuthatch	*Sitta carolinensis*
Wild turkey	*Meleagris gallopavo*
Wood duck	*Aix sponsa*
	Mammals
Black bear	*Ursus americanus*

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[1] Names based on Little, Elbert L., Jr., 1979, *Checklist of United States Trees* and Fernald, M. L., 1950, *Gray's Manual of Botany*.

[2] Bird names according to Robbins, Chandler S., B. Bruun, H. S. Zin, and A. Singer, 1966, *Birds of North America*; and mammal names according to Burt, W. H. and R. P. Grossenheider, 1964, *A Field Guide to the Mammals*.

Deer mouse	*Peromyscus maniculatus*
Eastern chipmunk	*Tamias striatus*
Eastern gray squirrel	*Sciurus carolinensis*
Flying squirrel	*Glaucomys volans* *Glaucomys sabrinus*
Fox squirrel	*Sciurus niger*
Raccoon	*Procyon lotor*
Redback vole	*Clethrionomys grapperi*
White-footed mouse	*Peromyscus leucopus*
White-tailed deer	*Odocoileus virginianus*

PRESCRIBED FIRE ON SLOPING TERRAIN IN WEST TENNESSEE TO MAINTAIN LOBLOLLY PINE (PINUS TAEDA L.)[1/]

Peter de Bruyn and Edward Buckner[2/]

Abstract.--Prescribed burning in a 22-year-old loblolly pine plantation killed 40 percent of the understory hardwoods and reduced fuel levels approximately 43 percent. Soil pH increased following spring and summer burns, but decreased following the fall burn. Burning times in sampling transects ranged from 30 to 245 minutes, depending on burn type, slope percent, and wind speed.

INTRODUCTION

Tennessee is in a transition position between the Central Hardwood Region, dominated by various oak-hickory associations, and the Southern Pine Region where the yellow pines are dominant. Most of Tennessee's commercial forestland is on upland sites, with oak-hickory the dominant cover type; over 90 percent of the forest cover is hardwoods. According to the forest survey, however, approximately one-half of the commercial forestland in Tennessee will be most productive if managed for pine (Wells, et al., 1974).

Over the last three decades forest industries have converted thousands of acres of Tennessee's upland hardwood forests to pine plantations. This trend continues and represents the most intensive forestry currently being practiced in the state.

Attempts to convert hardwood stands to pine are hampered by the aggressive seeding and rootsprouting of hardwoods. The intensive site preparation measures currently being used to control unwanted hardwoods may alter soil properties sufficiently to reduce productivity. Most of the older pine plantations in this region have aggressive hardwood understories that compete for soil moisture and nutrients and will make pine regeneration more difficult and expensive.

Greater industrial demand for pines and their greater productivity on most upland sites in this region make the natural progression from pines to hardwoods economically undesirable. Pines can be maintained only by repeated disturbances that discriminate against hardwoods. The greater susceptibility of hardwoods to fire damage provides the forest managers with an economical tool for maintaining pine on sites that would otherwise progress toward a hardwood climax (various oaks on most upland sites in Tennessee).

While a great deal is known about the behavior and effects of prescribed fire in the deep South, it has been little used in the rolling to steep terrains characteristic of most of Tennessee. Aggressive hardwood competition and high fuel levels in the pine plantations now common over much of Tennessee make prescribed fire an attractive management tool. Forest managers need safe and effective guidelines for its use in this region.

METHODS

The objectives of the study were to determine the effects of selected methods of prescribed burning on: 1) the hardwood understory, 2) nutrient mobility in the soil, 3) fuel levels, and 4) the growth rate of plantation pines. A 22-year-old loblolly pine (Pinus taeda L.) plantation in West Tennessee was selected for this study.

Treatment plots of approximately 3/4 hectare were located on the west and east sides of a north-south oriented ridge. Burns were conducted in each season except winter when burning was not possible due to adverse weather conditions. Each seasonal test consisted of 4 contiguous treatment plots, 2 on the west facing slope and 2 on the east. On each slope one burn originated from the

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[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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ridge crest and the other from the base of the slope. Since desirable burning conditions for this region call for 3-8 km/h winds out of the west, this arrangement permitted evaluation of headfires burning both up and downslope and backfires burning both up and downslope.

In each treatment plot the hardwood understory was sampled along 4 transects (3 meters wide by 50 meters long) oriented up and downslope. In each transect the hardwood understory was inventoried according to species and size class. Following burning each hardwood identified in the pre-burn inventory was assigned to one of the following classes: 1) killed, 2) killed back but sprouting, and 3) alive. All plantation pines within transect boundaries were measured and tagged prior to burning. Remeasuring took place during the dormant season over a 2-year period. Mortality of the croptrees was recorded at each reinventory.

Soil samples were collected prior to and after burning to determine the release of selected nutrients and the effect of burning on soil pH. Six sampling sites were chosen in each treatment plot, 2 on the upper-, 2 on mid-, and 2 on the lower-slope positions. At each sampling point three samples were collected representing the 0-10 cm, 11-20 cm, and 21-30 cm depths.

Forest floor samples were collected at 4 locations in each treatment plot prior to burning to determine the amount of fuel per hectare and its moisture content at burning time. The same sampling scheme was used after burning to determine the reduction in fuel per hectare due to burning.

During each burn relative humidity, ambient air temperature, and wind velocity and direction were monitored. The duration of each burn (time required for the fire to travel the length of the transects) was recorded. Thermocouples were buried beneath the forest floor, at its interface with the mineral soil, at 3 positions on the slope to determine the relative temperatures attained in the different burn types.

RESULTS

Weak and/or variable winds during burns prevented evaluation of headfires and backfires as originally planned. The time required for each fire to burn the 50 meter length of the sampling transect (rate of burn) was substituted as an integration of slope and windspeed effects in evaluating results.

Fuel reduction was not related to the rate of burn, but was greater when both fuel moisture and relative humidity were low. The greatest reduction in fuel levels resulted from the fall burn of 1978, an extremely dry fall for this region, where fuels were reduced 58 percent compared to approximately 40 percent for the other burns. Fuel reductions in treatment plots ranged from 20 to 70 percent.

Although highly variable, soil P increase averaged approximately 3 kg/ha following burning (Table 1). The increase was greatest at the 0-10 cm level, and was the smallest in the 11-20 cm level but increased again in the 21-30 cm level. These changes probably reflect soil textural differences with higher clay and organic matter contents associated with increased soil P. Soil K changes were highly variable and, as a percentage of that extracted in the soil test procedure, overall increases were much smaller than for P. Soil pH decreased mainly following the fall burn, while there was a slight increase in soil pH following summer and spring burns. This may be associated with the extremely dry conditions and hot burns that fall.

Table 1.--Changes in soil phosphorus and potassium following burning (kg/ha).

	Depth(cm)	Preburn	Postburn	Change
PHOSPHORUS				
	0-10	5.8	9.9	+4.1
	11-20	5.3	5.7	0.4
	21-30	5.7	7.8	+2.1
POTASSIUM				
	0-10	111	117	+7
	11-20	137	148	+11
	21-30	182	185	+3

Species susceptibility to fire varied greatly (Table 2). While only 21 percent of the sassafras

Table 2. Species arranged according to decreasing susceptibility to fire.

SPECIES	MORTALITY PERCENT
eastern red cedar (*Juniperus virginiana* L.)	93
sugar maple (*Acer saccharum* Marsh.)	85
yellow poplar (*Liriodendron tulipifera*)	80
wild black cherry (*Prunus serotina* Ehrh.)	75
red maple (*Acer rubrum* L.)	61
dogwood (*Cornus florida* L.)	58
witch-hazel (*Hamamelis virginiana* L.)	54
vaccinium (*Vaccinium* spp.)	50
viburnum (*Viburnum* spp.)	50
red oak (*Quercus* spp.)	41

Table 2 (cont.)

SPECIES	MORTALITY PERCENT
white oak (*Quercus* spp.)	40
sweetgum (*Liquidambar styraciflua* L.)	34
ash (*Fraxinus* spp.)	28
elm (*Ulmus* spp.)	25
black gum (*Nyssa sylvatica* Marsh.)	23
hickory (*Carya* spp.)	22
sassafras (*Sassafras albidum* Nutt.)	21

stems were killed; 93 percent of the eastern red cedar stems were killed. Susceptibility to fire was not found to differ among seasons.

Fuel reduction and hardwood mortality were greatest in the fall 1978 burns when forest fuels were extremely dry. This relationship among fire intensity, fuel reduction, and hardwood mortality appeared to hold for conditions prevailing in the three seasons tested (Table 3). Relative humidity and fuel moisture appeared to interact to control fire intensity.

Table 3.--Relationship between burning conditions and burn effects.

	BURNING CONDITION		BURN EFFECT	
BURN SEASON	RELATIVE HUMIDITY	FUEL MOISTURE CONTENT	FUEL REDUCTION	HARDWOOD MORTALITY
	PERCENT	PERCENT	PERCENT	PERCENT
Summer 1978	60	24	40	35
Fall 1978	35	24	58	44
Spring 1979	30	42	42	41

The diameter growth of plantation pines was not related to any of the burn effects. However, croptree mortality was related to fire intensity. Fifty-one croptrees died following the fall burn in 1978 in which there was a 58 percent fuel reduction, and 28 croptrees died following the summer burn that year in which there was a 40 percent fuel reduction.

Thermocouple readings varied greatly during the summer and fall burns; maximum temperatures at the litter-mineral soil interface ranged from 34 to 100+ degrees Centigrade. Fluctuations during the spring burn 1979 were far less (48 to 75 degrees Centigrade) due to a higher fuel moisture content.

DISCUSSION AND CONCLUSION

Restricting prescribed burning to periods of "optimum" fuel moisture and weather conditions is difficult if not impossible, especially when large acreages are involved. The small and highly variable differences found in this study among seasons, fire type, and rate of burn suggest that "fire is fire" and getting burning accomplished should be the primary concern rather than waiting for "optimum" conditions. Experience has shown that "optimum" burning conditions rarely occur due to the large number of uncontrollable variables, most of which are weather related.

In general, hardwood control and fuel reduction was best accomplished in the fall 1978 burns which were carried out when the fire danger rating was high. Since fire type had little effect, it appears that the primary objectives for using prescribed fire in the hilly terrain of Tennessee are best met by using fire types that are easily controlled (e.g., backfires downslope) when forest fuels are highly combustible.

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LOW INTENSITY BURN PRIOR TO BEDDING AND PLANTING SLASH PINE IS OF LITTLE VALUE[1]

Dale D. Wade and Lawrence P. Wilhite[2]

Abstract.--On a Lower Coastal Plain site in Georgia, unburned plots and plots that had received a low-intensity broadcast burn were drum chopped, bedded, and machine planted to slash pine *(Pinus elliottii* Engelm. var. *elliottii)*. Measurements through 6 years after planting suggested that burning had little or no effect on survival, fusiform rust infection, overtopping, or growth of pine seedlings. Independent of the effects of burning, pine growth was significantly reduced by early, transitory overtopping and by proximity to bluestem grasses or bitter gallberry.

INTRODUCTION

For many decades, foresters have burned clearcut southern pine sites to prepare them for pine planting. These prescribed fires reduced the wildfire hazard, facilitated planting, and increased survival and growth of the pine seedlings. During the last few decades, even better performance of pines has been achieved by following the burn with various types and intensities of mechanical site preparation. We question the benefits of such burning when conditions preclude a hot fire and when the area is also scheduled for intensive mechanical treatment.

The study described here was designed to measure the benefits, if any, of a light intensity fire prior to bedding to prepare a site for planting of slash pines *(Pinus elliottii* Engelm. var. *elliottii)*. Observations on the effects of competing vegetation on seedling growth are also reported.

The study area is on the Lower Coastal Plain in Echols County, Georgia, on land leased by St. Regis Paper Company of Jacksonville, Florida. Soil is a poorly drained Leon fine sand. A natural stand of slash pine was harvested from the area 6 years before it was site prepared.

Observations and measurements taken on thirty 1/4-milacre plots just prior to preparation revealed that the vegetative cover of the site consisted mostly of bitter gallberry, bluestem grasses, saw palmetto, blueberry bushes, fetter bushes, and threeawn and dropseed grasses.[3] The ovendry weight of vegetation, or standing fuel, was estimated to be 4.1 tons per acre.

During the 6 years between clearcutting and site preparation, most of the logging debris, and all of the pine-needle litter, had decomposed. The litter layer, therefore, was composed mostly of fallen leaves from shrubs and dead herbaceous material. It was estimated to weigh less than 1/2 ton per acre.

METHODS

Site Preparation and Planting

St. Regis scheduled the site for broadcast burning in August 1971, to be followed by scarification with an offset, tandem-drum chopper and the raising of 6-inch-high beds on 12-foot centers with a bedder-packer. After allowing several weeks for soil settling, 1-year-old nursery seedlings of slash pine were to be planted 6 feet apart along the beds with a Lowther drag-type planting machine, in which a planter rides facing forward and inserts seedlings into the planting slit.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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[3] Scientific names of competing plants are provided in table 1.

To accomodate our study, four 1/2-acre blocks were established on the study site before burning, and half of each block was randomly chosen to remain as an unburned but chopped and bedded plot.

Firelines were plowed in August 1971 to protect four 1/4-acre plots from the broadcast burn that would be set as soon as conditions were favorable. The next several months, however, illustrated one of the problems that prompted us to establish this study: rain began falling whenever fuel moisture conditions indicated that the site would soon be dry enough to burn.

The area finally dried out enough to carry a fire in early November. The ensuing fire traversed between 60 and 81 percent of the four burned plots, topkilling the grasses, forbs, and smaller shrubs. We estimated fire intensity to be less than 50 BTU's per second per foot of fire line. All unburned portions of the burned plots were mapped so that after planting these portions could be excluded from the 100-tree measurement plots. The entire study area was chopped in January, bedded in February, and planted in March of 1972.

Measurements

After planting, the distances between planting positions were measured to determine if burning facilitated construction of beds and thus permitted more uniform planting spacing. Also, each measurement seedling was judged to be either well planted, deep planted, shallow planted, or unplanted (released from the planting machine at the proper distance, but not actually planted).

Seedling heights and diameters and incidence of cankers (caused by *Cronartium fusiforme* Hedgc. & Hunt) were recorded periodically through 6 years after planting.

Changes in understory fuel weight and understory plant species were documented on two 1/4-milacre plots located in each treatment plot. Percent crown cover of the various understory species was estimated using a light table, a dot grid, and stereo-pairs of 35-mm color transparencies. These transparencies had been taken downward from a portable camera support over permanent quadrats as described by Pierce and Eddleman (1970).

Competition to the pines, including overtopping, was periodically evaluated by recording the species of plant within 1 foot of each surviving measurement pine that appeared to be offering the most competition to that pine.

Statistical Analyses

Analyses of variance for a completely randomized design were used to compare differences between the burned and unburned treatments. Factors examined included quality of planting; height, diameter and survival of the pines; incidence of fusiform cankers; percent of pines overtopped by competing vegetation; weight of understory fuels; and frequencies of various understory species.

Data from the burned and unburned plots were combined for analysis of effects of overtopping species on height and diameter of pines. Again, differences were evaluated by analysis of variance.

Differences between percent crown coverage of burned and unburned understories were analyzed by a t-test.

RESULTS AND DISCUSSION

Seedling Performance

Seedling spacing along the planting rows averaged 5-1/2 feet for both the burned and unburned plots, but the standard deviation in spacing was actually greater for the burned plots. Burned plots contained more well planted seedlings than the unburned plots (92 versus 88 percent), but the difference was not statistically significant. Thus, burning before mechanical preparation resulted in little, if any, improvement in planting.

A comparison based upon all measurement positions 6 years after planting showed the following:

	Burned plots	Unburned plots	Significant level of difference
6th Year:			
percent survival	89	83	NS
height in feet	15.6	16.6	NS
DBH in inches	2.65	2.85	NS

These differences are not sufficient to judge one treatment better than the other.

By 6 years after planting, 5 trees on the unburned plots had been killed by fusiform rust cankers and 18 survivors had stem cankers, whereas no trees had been killed by fusiform on the burned plots and 16 survivors had stem cankers. The differences, however, were not statistically significant.

Understory Development

Immediately after chopping and bedding, both the burned and unburned plots were essentially devoid of standing vegetation. Recovery of vegetation appeared to be faster on the unburned plots, but differences between treatments in height and density of competing vegetation and in numbers of pines overtopped were not statistically significant.

Bitter gallberry bushes and bluestem grasses dominated the understory before preparation. They still dominated it after preparation (table 1). Saw palmetto, blueberry bushes, fetter bushes, and threeawn and dropseed grasses were less prevalent after site preparation than before. The other species listed in table 1 were encountered too infrequently to judge the effect of site preparation upon their numbers. In general, however, the understory on both the burned and unburned plots three years after preparation looked much as it had before preparation.

No significant differences between burned and unburned plots were found in the frequencies of bitter gallberry, or bluestem grasses, or threeawn plus dropseed grasses or panic plus paspalum grasses. Frequencies of the other species listed in table 1 could not be statistically compared because they were absent from one or more plots.

Woody plant competition to pines on the burned plots, initially low, increased to almost that on the unburned plots by 6 years after planting (fig. 1). At no measurement, however, was the difference significant.

Table 1.--Species within 1 foot of the surviving pines that appeared to be offering the most competition to individual pines, expressed as percentages of planting positions with surviving pines.1/

Species or Species Groups	One year after planting		Three years after planting		Six years after planting	
	Burned	Unburned	Burned	Unburned	Burned	Unburned
	- - - - - - - -	- - - - - -	percentages	- - - - - -	- - - - - -	- - - - - - - -
WOODY PLANTS						
Bitter gallberry *(Ilex glabra* (L) Gray*)*	24.3	28.7	53.0	56.3	72.4	71.8
Southern waxmyrtle *(Myrica cerifera* L. var. *cerifera)*	0.3	1.4	0.9	2.0	2.9	4.8
Fetter bushes *(Lyonia* spp. Nuttall*)*	1.5	1.3	1.4	1.4	0.7	0.0
Redbay *(Persea borbonia* (L) Sprengel*)*	0.3	0.5	0.6	1.0	0.6	2.4
Sweet pepperbush *(Clethra alnifolia* L.*)*	2.8	2.1	0.3	0.3	0.3	0.0
Chokeberry *(Sorbus arbutifolia* (L) Heynhold*)*	0.9	4.9	0.0	1.3	0.0	0.0
Saw palmetto *(Serenoa repens* (Bartram) Small*)*	0.4	0.8	1.5	2.1	0.6	1.5
Sweet gallberry *(Ilex coriacea* (Pursh) Chapman*)*	0.0	0.3	0.0	1.0	0.0	0.0
Blueberries *(Vaccinium* spp. L.*)*	3.1	5.9	0.6	0.0	0.0	0.0
Red maple *(Acer rubrum* L.*)*	0.3	0.0	0.3	0.0	0.3	0.4
Grape *(Vitis* spp. L.*)*	0.0	0.0	0.0	0.0	0.0	0.3
Greenbrier *(Smilax* spp. L.*)*	0.5	0.0	0.0	0.0	0.0	0.0
HERBACEOUS PLANTS						
Bluestem grasses *(Andropogon* spp. L.*)*	17.0	26.4	38.4	33.1	22.2	18.9
Threeawn and dropseed grasses *(Aristida* spp. L. and *Sporobolus* spp. R. Brown*)*	5.6	3.1	0.3	0.3	0.0	0.0
Panic and paspalum grasses *(Panicum* spp. L. and *Paspalum* spp. L.*)*	29.2	10.2	0.0	0.0	0.0	0.0
Other grasses and grasslikes (Poaceae, Cyperaceae, and Juncaceae)	8.8	7.1	2.6	1.2	0.0	0.0
Composites (Asteraceae)	3.3	1.6	0.0	0.0	0.0	0.0
Redroot *(Lachnanthes caroliniana* (Lam.) Dandy*)*	0.3	2.3	0.0	0.0	0.0	0.0
Ferns	0.0	0.7	0.0	0.0	0.0	0.0
Unidentified Herbaceous species	0.8	1.4	0.0	0.0	0.0	0.0
NO COMPETING PLANTS WITHIN 1 FOOT OF PINES	0.6	1.3	0.0	0.0	0.0	0.0
TOTAL PERCENT	100.0	100.0	99.9	100.0	100.0	100.1

1/For example, the first numerical entry indicates that 24.3 percent of the pines surviving on the burned plots 1 year after planting appeared to be receiving more competition from bitter gallberry than from any other species.

The measurement of crown coverage using vertical stereophotographs indicates that vegetative recolonization of the study site was rapid, with more than 90 percent of the site covered with vegetation 2 years after site preparation. Percent cover of herbs peaked at 2 years, then decreased during the next year as coverage of woody plants increased. Neither the woody nor the herbaceous coverage differed significantly between the burned and unburned plots. Graphic presentation of this coverage (fig. 2) suggests, however, as did the competition data in figure 1, that burning plus mechanical preparation resulted in more effective initial control of woody plants than did mechanical preparation alone.

Of the 436 well-planted pines not overtopped by other vegetation 1 year after planting, only 2 subsequently became overtopped (temporarily), and only 6 died between the first and sixth years after planting. Of the 158 well-planted pines overtopped at 1 year, only 3 were still overtopped at 3 years, 2 were overtopped at 4 years, 1 was overtopped at 6 years, and only 2 died between the first and sixth years. Despite its transitory nature, the overtopping, or something associated with it, reduced height and diameter growth through 6 years after planting:

Years since planting	Pines overtopped at 1 year	Pines not overtopped at 1 year	Significant level of difference
	- - - - - - height in feet - - - - - -		
0	0.7	0.7	NS
1	1.0	1.1	0.005
4	8.0	9.0	0.005
6	15.0	16.6	0.05
	- - - - - - DBH in inches - - - - - -		
6	2.50	2.85	0.05

The most meaningful of the competition measurements appeared to be the one made 6 years after planting among the well-planted surviving pines that were not infected with stem canker. In that measurement, 73 percent of the pines were judged to be receiving their major competition from bitter gallberry, 19 percent from bluestem grasses, and the remaining 8 percent from saw palmetto, fetter bush, waxmyrtle, redbay, red maple, or grape vine. Average height and diameter of the pines varied with the species of the competitor:

Competitor	Pine Height	Pine DBH
	feet	inches
Bluestems	15.3	2.6
Gallberry	16.4	2.8
All others	17.3	3.1

Pines competing with the bluestems (chiefly *Andropogon virginicus* L. and *A. capillipes* Nash) averaged significantly shorter (0.05 level) and smaller in diameter (0.025 level) than pines competing with those species referred to collectively as "all others". The growth retarding effect of the bluestems upon slash pine may be less of a competition effect than an allelopathic effect, considering that Priester and Pennington (1978) found that water extracts from the shoots of *A. virginicus* slowed the height growth of loblolly pine (*Pinus taeda* L.) seedlings.

Pines competing with bitter gallberry were significantly smaller in diameter (0.025 level) but not significantly shorter than pines competing with the "all others" category. Pines competing with bitter gallberry did not differ significantly in height or diameter from pines competing with bluestems.

SUMMARY AND CONCLUSIONS

Growth of slash pine seedlings was signficantly reduced by proximity to bluestem grasses or to bitter gallberry, or by temporary overtopping by any competing plants. This information may be of more direct use to the forester researcher than to the forest manager.

Of more immediate use to the forest manager are the results indicating that prescribed fire before mechanical preparation may not be necessary. Effects of the low intensity fire before chopping, bedding, and planting had neither practical nor statistical significance. A fire of higher intensity might have produced differences of statistical and economic significance. The fact remains, however, that without any prescarification fire, slash pine averaged 16 feet tall and 83 percent survival 6 years after planting. Under the conditions of the study, an entirely adequate plantation was established without burning!

Because most of the logging debris had decomposed and the mechanical treatments had adequately controlled the competition, burning was not cost effective. Prescarification burning probably is equally unnecessary on sites where most of the combustible material has been removed by whole-tree harvesting. Even on sites with more debris, a prolonged wait for good burning conditions could result in the cost of burning outweighing its benefits. If such a wait seems likely, and a mechanical treatment that will allow acceptable stand establishment at an acceptable cost is available, burning should probably be foregone.

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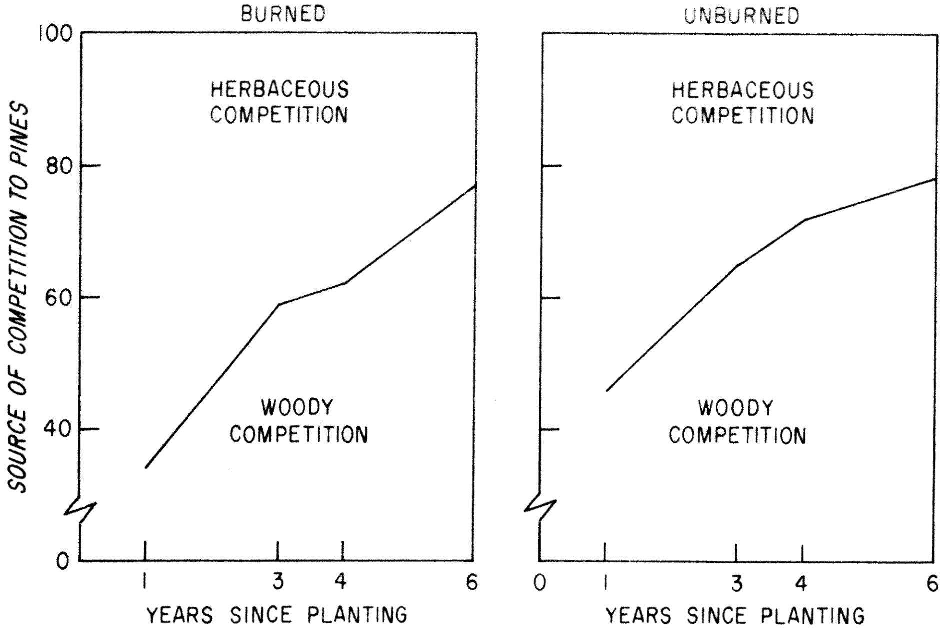

Figure 1.--Trend toward woody competition with time since site preparation.

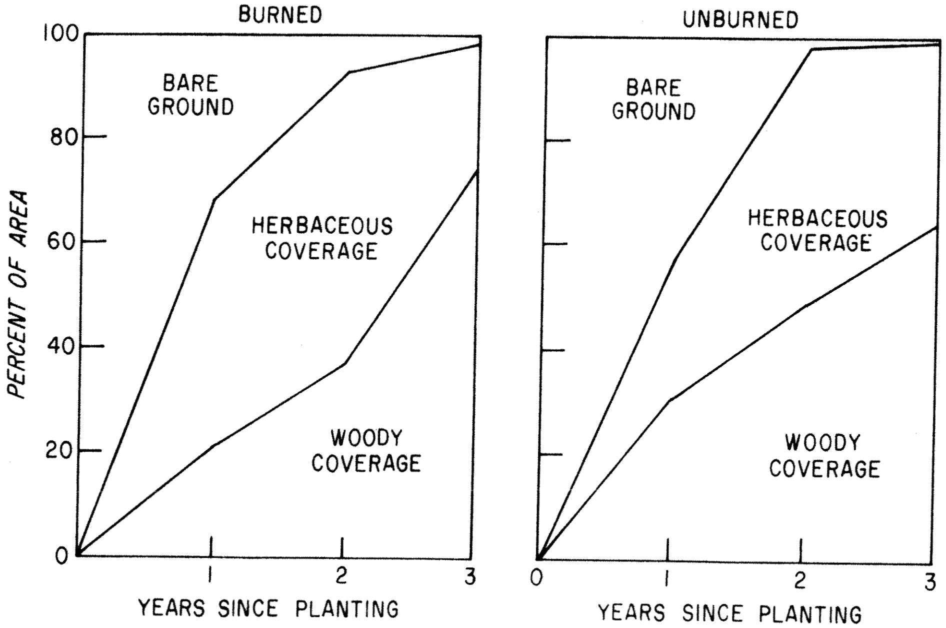

Figure 2.--Trend toward woody understory coverage with time since site preparation.

BOTTOMLAND HARDWOODS RESEARCH ON SITE PREPARATION, PLANTATION ESTABLISHMENT, AND CULTURAL TREATMENTS, AT THE SOUTHERN HARDWOODS LABORATORY[1]

Harvey E. Kennedy, Jr.[2]

Abstract.--The South contains about 219 million acres of forests, 70 million acres of which are most productive when managed as hardwoods. Bottomland hardwoods cover about 22 million of this 70 million acres. Hardwood plantation management has been increasing during the last few years, but natural stand management still accounts for more than 99 percent of hardwood production in the South. This paper summarizes research and experience at the Southern Hardwoods Laboratory that have solved some of the problems in plantation management. Proper site selection, good site preparation and cultivation, high quality seedlings, and proper planting techniques are musts if hardwood plantations are to be successful. Planting large seedlings may reduce costs of site preparation and cultivation, as well as get more desirable seedlings into an area.

The South contains more than 532 million acres of land. Forests cover 41 percent of this land area. Of the 219 million acres of forest land, 70 million acres are most productive when managed for hardwoods. Bottomland hardwoods total 22 million acres, with upland and mountain hardwoods comprising the remaining 48 million acres. In 1977, 54 percent of the hardwoods harvested in the eastern United States came from the South.

Hardwoods were the primary object of earliest forest management practices in the United States, but the emphasis shifted rapidly to conifers that were demanded by industry and more easily managed. High-grading, fire, grazing, and poor markets for intermediate products have caused hardwoods to be neglected in forest management.

Recently, the demand for hardwood products such as furniture, pallets, pulpwood, construction material, and fuelwood has increased. To meet the higher demand for hardwood products, better forest and plantation management with supplemental planting of desired species in natural stands will have to be practiced.

This paper summarizes some research results on plantation establishment, site preparation, and cultural treatments at the Southern Hardwoods Laboratory.

SITE PREPARATION AND CULTIVATION

One of the first prerequisites for successful hardwood plantations is proper site selection. Species must be adapted to the site. The most desirable sites would be moist but well-drained sandy loams and silt loams in most southern river bottoms. Best growth for all species occurs at sites receiving ample moisture during the growing season (McKnight 1970). Many hardwoods can withstand flooding during the dormant season if the water is cool and moving or does not stay on the ground for extended periods during the growing season. Our experience has shown that flooding during the first growing season can be very damaging to young hardwood plantations, but trees can withstand prolonged flooding after the first growing season.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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Sites which are recommended for planting are inherently fertile, and the climate in the South is well suited for excellent growth. Weeds as well as trees grow rapidly, but most hardwoods are intolerant and can stand little if any competition for light and moisture when trees are young. Careful site preparation is essential to get trees established and to make weed control easier during the first growing season (McKnight 1970).

Site preparation is the most costly phase in establishing southern bottomland hardwood plantations. In 1976, contract clearing, raking, windrowing, burning, and disking costs were about $150 per acre (Johnson 1977). This cost may be as much as $200 or more per acre now. Such intensive site preparation is required to do the straddle cultivation essential to achieve nearly complete control of vines, weeds, sprouts, and other seedlings while planted seedlings are being started. Also added to the clearing costs would be $50-60 per acre for first-year cultivation. The plantation needs to be cultivated at 3- to 4-week intervals five to six times the first growing season. Clearing costs under contract programs may be bettered by companies using their own equipment.

Best sites for most hardwoods are on land recently cleared of timber. The soil is in good physical condition and weeds are usually not plentiful (McKnight 1970). Trees should be sheared and the site thoroughly cleaned and disked to facilitate planting and first-year cultivation. Stumps left after logging and standing unmerchantable trees and shrubs should be cut at or just below the groundline. The sheared material should be windrowed and burned. Some of the debris from near the edge of the clearing operation can be used to construct crude fences to exclude deer if they are a problem. These fences need to be 10 to 12 feet in height and about 20 feet across the base.

Use of "old-field sites" will eliminate the cost of clearing. Experience and research have shown, however, that these sites need to be deep plowed (fallowed) before planting. Plowing breaks the sod, reduces competition from weeds, eliminates compaction, aerates the soil, and allows rapid infiltration of moisture from rainfall. Baker and Blackmon (1978) reported on summer fallowing as a simple technique for improving old-field sites for cottonwood. This technique should also work for other hardwoods.

For cultivation, most forest managers prefer tractors of about 100 horsepower, a size large enough for clearing, fallowing, and planting, but small enough for cultivating (Kennedy and Henderson 1976). One tractor per 200 acres is required for adequate results. Commercial planters are straddle cultivating one row at a time with conventional front-mounted farm cultivators until trees are about 2 feet tall. Front-mounted cultivators allow the driver to have better visibility and control and therefore cause less damage to trees than with rear-mounted cultivators. Cultivators equipped with chisel- or shovel-type plows allow tillage close to young trees without appreciable damage. Equipment most frequently used consists of: (1) large front-mounted cultivators with 19 to 21 shanks that will straddle one row while covering the space within rows, or (2) offset front-mounted cultivators equipped with 5 to 6 shanks that straddle the row while covering a small area on each side; with this system, a disk or spring-tooth harrow drawn behind the tractor covers the area between rows. When trees are too tall to straddle, the cultivators are removed, and tillage between rows is accomplished with a disk or harrow.

PLANTATION ESTABLISHMENT

In the past few years plantation acreages have been increasing and today there are between 100,000 and 150,000 acres (Johnson 1977). However, in the eastern United States, natural stands still account for over 99 percent of the hardwood production.

Research and experience have solved many of the problems of growing cottonwood and other hardwoods in plantations (Johnson 1977). Species being grown in plantations today are cottonwood, sycamore, sweetgum, green ash, and black walnut.

After site preparation, the area is ready for planting. The planting operation can be accomplished by hand with dibbles or with machines, whether planting hardwood seedlings or cottonwood cuttings. Good planting techniques and quality seedlings are a must if the plantation is to be a success. Forest owners are now looking for quality seedlings with a rootcollar diameter at least 1/4- to 3/8-inch or larger and tops 30 to 36 inches tall (McKnight and Johnson 1980, Weber 1972). Cottonwood cuttings should be 3/4- to 1-inch at the large end and a minimum of 3/8-inch at the small end.

High site preparation cost is probably the main deterrent of hardwood plantation establishment at this time. Ongoing research at the Southern Hardwoods Laboratory is aimed at overcoming the expensive site preparation and cultivation costs by planting large seedlings. Work is currently underway with cottonwood, sycamore, and four oaks. The objective is to improve early height growth by planting trees up to 3 years old, 10 to 15 feet tall, and 2 inches in diameter at the root collar (Johnson 1979). Trees have been planted with and without top and root pruning in 9-inch diameter auger holes. Other work is being done on growing large seedlings for 1 to 2 years in containers (9 inches diameter by 24 inches tall) and planting seedlings with undisturbed root systems. Potential early benefits are rapid early growth, planting trees large enough that cultivation can be kept to a minimum, and a planting height beyond the range of deer. Early results with this method are very encouraging.

BENEFITS OF CULTURAL TREATMENTS

At the Southern Hardwoods Laboratory, three levels of cultural intensities were tested with six hardwood species. Cultural intensities were: disk (clean cultivation), mow, and control (no treatment). Species were sycamore, green ash, cottonwood, sweetgum, Nuttall oak, and sweet pecan. After four growing seasons, trees in disked plots were significantly taller and had larger diameters than trees in mowed and control. There were no real differences between mowed and control. Disking increased heights from 42 percent for green ash to 130 percent for sycamore over trees in control plots. Diameter increases ranged from 144 percent for cottonwood to 240 percent for Nuttall oak.

Survival was best in disked plots (91 percent), with mowed next (80 percent), and control lowest (76 percent). Disked plots ranged from a low of 84 percent survival for sweetgum to 99 percent with sycamore. Green ash survived best in mowed and control plots with sycamore a close second.

Trees in disked plots had significantly higher foliar N and Ca concentrations and significantly lower P and Mg than trees in mowed and control plots. Trees in mowed plots had significantly lower K than control; those in disked plots were intermediate with no difference between mowed and disked. Although foliar nutrient concentrations were lower for some nutrients in trees in disked plots, if we assume weight to be proportional to size, then nearly twice as much of each nutrient would have been accumulated in trees in disked plots as in mowed and control. Cottonwood had the highest nutrient concentrations for most elements tested. Sycamore was lowest or tied for lowest for N, P, and K; fourth for Ca; and third for Mg.

Cultural treatments, particularly disking, did not cause any significant reductions in soil nutrient levels. One of the major benefits of disking was probably vegetation control. However, it also improves soil structure, water infiltration, gas exchange between the soil and atmosphere, organic matter, and nutrient availability.

SUMMARY AND CONCLUSIONS

Research and experience have solved many of the problems in planting cottonwood and other priority hardwoods. Our recommendations entail intensive site preparation and clean cultivation through at least the first growing season. Proper site selection, good site preparation and cultivation, high quality seedlings, and proper planting techniques are musts if hardwood plantations are to be successful. Planting large seedlings may reduce the costs of site preparation and cultivation. In addition to competition control, other benefits of disking include better soil nutrient and moisture availability, incorporation of organic matter and mineralization, gas exchange between the soil and atmosphere, and improved soil structure.

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SITE PREPARATION TREATMENTS AND NUTRIENT LOSS FOLLOWING COMPLETE HARVEST USING THE NICHOLSON-KOCH MOBILE CHIPPER[1]

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James H. Miller
Conrad Brewer

Abstract.--Site disturbance, vegetation control, and nutrient loss were assessed following complete biomass harvesting of a pine plantation by the Nicholson-Koch mobile chipper. Thirty-two percent of the soil area was significantly compacted to a 10 cm depth. Litter zone material showed a two-fold increase due to chips lost during harvest. Herbicide treatments (Tordon 10K and Velpar Gridball) were applied following harvest. Tordon controlled 84 percent of the hardwood resprouts during the first growing season and Velpar 37%. Tension-cup and -plate lysimeters were used to monitor percolation losses from the soil. During the first 5 months, treatments accelerated losses of Ca, Mg, K, Na, PO_4, NO_3, SO_4, and HCO_3. Loss due to Tordon treatment was greater than chipping alone, for all nutrients analyzed.

As current energy sources continue to increase in cost and decrease in availability, attention has turned toward wood as a renewable fuel source for wood processing and other industries. Nationally, the wood processing industry is 40 percent self-sufficient in energy production (Arola 1976) with the Southeast having the greatest potential but the lowest utilization at the present time. Complete biomass harvest for fuel is a developing reality (Koch and McKenzie 1976) but the concept raises questions regarding impacts on future site productivity. The engineering research work unit of the Southern Forest Experiment Station at Auburn, Alabama, is testing a complete biomass harvest system, the Nicholson-Koch Mobile Chipper (Koch and Savage 1980). A mobile-chipper test site was used in this study to assess site preparation potential, surface disturbance, and nutrient-loss impacts after complete biomass harvest.[3]

STUDY AREA

A complete biomass harvest was performed during April, 1980 on a 1-ha study site in the Forestry Department Woodlot, Auburn University. The soil series was a Blanton loamy sand with well developed litter (8 cm) and humus (5-10 cm) layers. Slope on this site ranged from 5-15% with two old terraces on the steeper slopes. A partially-filled gully runs across the center of the area, resulting from past cultivation.

A plantation of 53-year-old mixed loblolly (*Pinus taeda*) and slash pine (*Pinus elliottii*) averaging 147 metric tons per hectare (m.t./ha) total standing crop comprised the overstory on

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If herbicides are handled, applied or disposed of improperly they may be injurious to humans, domestic animals, desirable plants, and pollinating insects, fish, or other wildlife, and may contaminate water supplies. Use herbicides only when needed and handle them with care. Follow the directions and heed all precautions on the container label.

[3] All further references to harvesting on this site are made with the assumption that all standing trees, shrubs, and vegetation were removed at or just above the soil surface; no root harvest occurred.

approximately half of the area. A shortleaf pine (Pinus echinata) stand averaging 87 m.t./ha covered the other half of the test site. Prevalent mid-story species were southen red oak (Quercus falcata), water oak (Quercus nigra), sweetgum (Liquidambar styraciflua), persimmon (Diospyros virginiana), dogwood (Cornus florida), red maple (Acer rubra), and high bush blueberry (Vaccinium sp.).

METHODS

A complete block experimental design was used with three blocks and five .05 ha treatment plots per block. Four of the five treatment plots were completely harvested before applying additional treatments to control hardwood resprouting. The fifth treatment plot in each block remained unharvested and untreated.

The following treatments were assigned randomly and initiated on the four harvested plots in each block:

1. Velpar Gridball - hand applied in a grid pattern at 1.3 kg/ha active ingredient (1 cc formulation[1]).
2. Tordon 10K - using commercial fertilizer spreader with a random scatter effect (small pellet[2]), applied at 5.6 kg/ha a.i.
3. Chipped only - no additional vegetation control measures initiated after harvesting (this plot to serve as a baseline for vegetation response to complete harvest).
4. Windrowing - land clearing by crawler-tractor with a straight blade.

Herbicide treatments were applied on June 18, 1980 after resprouting had begun. Windrowing is scheduled to begin in the fall (1980) prior to winter planting of loblolly pine seedlings.

In the following sections, study methods and results will be presented jointly under separate headings.

SURFACE DISTURBANCE

The degree and coverage of surface disturbance was assessed using seven categories, modified from Dyrness (1967).

1. Undisturbed--the humus layer still in place and no evidence of compaction.
2. Slightly disturbed--three conditions fit this class:
   a. Humus removed and mineral soil exposed;
   b. A1-horizon soil, humus layer, and/or chips intimately mixed with about equal proportions;
   c. A1-horizon soil deposited on top of litter.
3. Deeply disturbed--A1-horizon removed and A2-horizon or deeper soil layers exposed.
4. Compacted (depressed)--obvious compaction due to passage or a wheel and/or track.
5. Debris pile--mixture of debris and chips greater than 10 cm deep.
6. Soil deposition--eroded mineral soil deposited on soil surface.
7. Non-soil areas--stumps or logs.

Five 50- to 60-m transects were installed across the test site at regular intervals and the surface condition at 1-m spaced points was categorized into disturbance classes. Soil core samples were extracted in pairs from compacted (depressed) points and from undisturbed points within 30 cm at 0-5 cm and 5-10 cm depths.[3]

Results from the soil-surface survey are tabulated below.

Classes	Covered (%)
Undisturbed	25.3
Slightly disturbed	28.8
Deeply disturbed	1.1
Compacted	32.4
Debris piles	7.1
Soil deposition	2.8
Non-soil	2.5

Compaction is the most prevalent disturbance affecting about one-third of the area. This is less than a theortical maximum calculated from track- and chassis-width measurements in a complete harvest. If the inside track of the mobile chipper and/or wheels of a towed chip wagon followed over the outside track patch of the previous swath then 44 percent of the area would be compacted, while overlapping swaths would result

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[1] A 10% active ingredient pellet of hexazinone manufactured by E.I. Dupont de NeMours and Company.

[2] A 10% active ingredient pellet of picloram manufactured by Dow Chemical Company.

[3] Compaction data furnished by Anthony L. King, formerly with the Southern Forest Experiment Station, presently with Agricultural University, Kenya, Africa.

in 66 percent compaction. Our findings is less than the theoretical compaction potential owing to ground protection afforded mainly by chips from the feller bar operation and also limbs and surface roots. Differences in bulk density between compacted and disturbed soils were compared using paired t-tests and were found significant ($p \geq 0.01$) at both the 0.5 cm and 5-10 cm depths. Mean bulk density at the 0-5 cm depth was 1.54 g/cm^3 for compacted and 1.37 g/cm^3 for undisturbed conditions and at the 10 cm depth 1.58 and 1.42, respectively.

Hatchell (1970) reported that increases in bulk density from 0.17 to 0.20 g/cm^3 in loamy sand and loam soils reduced shoot weights of 1-year-old loblolly pine by 33 to 43 percent and root weight by 40 to 55 percent. Such a reduction in growth for seedlings on one-third of the areas harvested by the mobile chipper may not occur due to diminution of compaction effects by continuous-furrow or dibble-planted seedlings. This has not yet been determined. Planting by dibble would be difficult on 7.1% of this area due to deep deposition of chips and twigs.

HUMUS AND LITTER

Humus and litter were sampled prior to mobile chipping and again following harvest. Samples measuring 0.09 m^2 (1 ft^2) were extracted at six systematically located points within each treatment plot before harvest, a total of 90 samples. Sample locations were 4 m from plot corners (45°) and mid points on the longest sides (90°), with post-harvest samples taken immediately adjoining pre-harvest sample locations. During pre-harvest sampling the distinct humus and litter layers were separated at the time of collections but post-harvest samples required mechanical separation by nested sieves of chips and twigs from both litter and humus. Ashing will be performed on pre-harvest humus samples and post-harvest humus and litter samples to adjust weights for the mineral soil component. Only humus samples have been ashed at this time.

The chipping operation added 4.5 m.t./ha of chips and twigs to the original litter layer which weighed 2.3 m.t./ha. This 195 percent increase, due principally to chips, is attributed to feller-bar operation and chip-loss during turns when the chip wagon was not aligned with the chip discharge duct on the chipper. Fewer turns on larger areas or better alignment should decrease this loss. The influence of this large influx of material to the forest floor and resulting impacts on the mineralization processes are not known. These low-nutrient, high cellulose chips should decompose slowly releasing nutrients more gradually. Most of the needle and twig component was removed from the site with harvest. Removal from a forest of the leaf, twig and needle components as typifies complete biomass harvest, may diminish the available nutrient supply necessary for future growth. Waide and Swank (1975) in their model of nitrogen cycling in a loblolly pine plantation located in North Carolina have indicated a 100 percent increase in nitrogen removal with complete tree harvesting. Additionally they found that with leaf, twig, and needle removal, a substantial decrease in yield may be expected in the third rotation. Cole et al. (1968) in a study of Douglar-fir (Pseudotsuga menziesii) indicated that complete tree removal would more then double nutrient loss from a site following harvest.

NUTRIENT LEACHING

This study has begun to quantify the losses due to leaching following complete biomass chipping and removal, by employing tension lysimeters. Two types of lysimeters were used; tension cup and tension plate.[1] Cups provide soil solution samples with minimum concentration bias due to ceramic adsorption or ion screening. Plates allow calculations of loss on an area basis. Description of these devices and installation procedures can be found in Miller (this same conference). Prior to installation all lysimeters were washed with distilled water to eliminate ceramic contaminants.

Leaching losses are being monitored on the following three treatment plots within each block: (a) unharvested check; (b) chipped only (completely harvested) plots[2]; and (c) complete harvest plus herbicide control (Tordon 10K at 5.6 kg/ha a.i.). Lysimeters were installed below the lateral rooting zone at 60 cm. All installations occurred during the 3-week period following harvest completion. Lysimeters were placed just below the maximum lateral rooting zone to reflect true losses from the system. Lysimeters were systematically grouped into two units, with a central plate, and two cups (three in the check) as satellites at a distance of 3.6 m within monitored plots. A total of 18 plates and 42 cups have been installed on this study site.

All devices are evacuated to 0.2 bars which approximates Field Capacity moisture tensions. Percolating water that is held with less than 0.2 bars of tension may pass through the ceramic elements to be collected. Precipitation inputs are being quantified by 1 recording and 2 non-recording gages on the area.

Calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) are being analyzed in soil solution and precipitation samples using standard techniques of atomic adsorption spectrophotometry.

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[1] Both lysimeters are modified versions of commercial models manufactured by Soil Moisture Equipment Corp., Santa Barbara, California.

[2] This treatment plot to serve as a baseline for nutrient response following complete harvest, with no additional attempt at vegetation control.

Sulfate (SO_4) determinations are by the barium-chloride gel technique (Tabatabai 1974). Phosphate (PO_4), nitrate (NO_3), bicarbonate (HCO_3), and pH are determined using standard methods (McRand et al. 1976).

A substantial increase in leaching loss has occurred due to complete tree chipping and removal (Table 1). The use of herbicide for resprout control has accelerated this loss for all nutrients studied except phosphorus which has shown only a small increase in loss due to herbicide treatment. Bicarbonate and nitrate are the most concentrated anions responsible for cation leaching in this soil system. This data indicate that ecosystem recovery and on-site nutrient immobilization have not yet begun. The difference between nutrient loss in chipped plots and that incurred with herbicide application is probably attributed to root development and nutrient uptake by the reassurging vegetation.

HERBICIDE CONTROL

First year vegetation control by herbicide treatments was assessed by complete stem counts within three treatments plots; Tordon, Velpar, and Chipped Only. Sprouts were categorized as either uninjured, injured or dead. A tabulation of mean total hardwood stems per hectare reveals further the effectiveness of treatments; Chipped plots averaged 17,200 stems, Velpar plots 14,700 and Tordon 11,700.

Tordon plots demonstrated the most effective early control for hardwood, shrub, and woody-vine regrowth (Table 2), averaging 84 percent of all stems counted as injured or dead. Those plots in which Velpar was applied demonstrated some vegetation control, but suppressed only 37 percent of all stems. The chipped-only plots (no herbicide applied)had the lowest incidence of stem death or injury, averaging only 5 percent. The average per hectare was 14,550 hardwoods, 7850 shrubs, and 5912 vines.

Tordon was most effective against blueberry, sweetgum, red maple and grape controlling over 95 percent of these sprouts. It was least effective against the oaks but controlled an impressive 71 percent.

Velpar has to date been less effective in vegetation control than Tordon. Greatest control by Velpar was found in red maple, while control in excess of 50 percent occurred only in the red oak group. The impact of damage to vegetation by insects, water stress, and disease in the Tordon and Velpar plots may be discounted. The highest per-species injury rate in the chip-only plots, though not attributable to herbicide action, was used to create a baseline for separating true herbicide damage from natural injury of death, in the Tordon and Velpar plots.

Table 1. Areal precipitation inputs and leaching losses for eight nutrients from a completely harvested mixed pine plantation on Blanton loamy sand, collections 5/10 to 10/11/80.

	Inputs[1/]		Losses		
Nutrients	Min.	Max.	Unharvested Check	Chipped	Chipped and Herbicide
	g/ha				
Ca	265	733	58	826	1355
Mg	337	487	46	574	786
K	874	2063	83	732	846
Na	1001	1295	220	1670	2495
NO_3-N	966	1778	60	1161	2363
PO_4-P	59	147	0	15	16
SO_4-S	2185	4972	9	834	2225
HCO_3-C	1297	1812	400	3719	4696

[1/] Minimum inputs calculated using the lowest concentrations of three raingages, presumably minimum additions of bird droppings and insects, and maximum inputs used mean concentrations.

Table 2. Early results of vegetation control from three treatments on a completely harvested mixed pine planatation, Auburn University Woodlot.

	Vegetation Control Treatments		
Species	Chip Only	Chip and Velpar	Chip and Tordon
	% Damage[1]	% Damage	% Damage
Hardwoods			
Red Oak[2]	6a[3]	53b	71b
Sweetgum	8a	40b	100c
Red Maple	8a	89b	100b
Others[4]	2a	37b	93c
Total	2a	47b	76c
Shrubs			
Blueberry	9a	28b	97c
Others[5]	6a	31a	59a
Total	8a	28b	92c
Vines			
Grape	4a	36b	97c
Greenbrier	4a	33b	70c
Total	5a	36b	84c

[1] Includes dead and injured.

[2] Refers to the Red Oak group with several species represented.

[3] Means in a row followed by a different letter are significantly different at the 5% level.

[4] Includes hickory, yellow poplar, persimmon, sassafras, black locust, elm, black cherry, blackgum, beech, magnolia, and American hornbeam.

[5] Includes hawthorn, sumac, and bayberry.

DISCUSSION

Forest managers have a responsibility to understand the balance and regulation of nutrient cycling in a forest ecosystem. Nutrient inputs by precipitation, mineral weathering, dry fallout and fertilization as well as losses by biomass removal, leaching and gaseous losses must be regulated by a modern management approach. Continued site productivity and the renewable nature of the forest resource depends upon this knowledge and regulation. The significance of harvest removal of nutrients may be most critical where complete biomass harvesting occurs and where on-site nutrient capital is low to marginal.

Several studies (Wells and Jorgenson 1975, Weetman and Weber 1972, Pritchett and Smith 1974) have demonstrated the significant increase in nutrient loss when whole tree harvest has occurred. Development of the Nicholson-Koch Mobile Chipper may make possible even greater utilization of the material typically left following harvest, while producing a corresponding increase in nutrient removal.

Future research will quantify major contributing components of the nutrient cycle on this site. Litter, humus, chip and soil nutrient budgets will be determined, while monitoring of leaching loss and precipitation input will continue. It may be important to note that when this or similar harvest systems are used, alteration of the cutting schedule to occur before spring leaf-out may contribute significantly to continued site productivity, especially on typically poor quality sites, Also, the importance of minor essential nutrients that have been removed through harvest may become critical to future site productivity, and therefore an attempt will be made to assess these losses in further efforts.

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DIRECTED-SPRAYING DICHLORPROP FOR PINE RELEASE[1]

Robert F. Lowery[2]

Abstract.--Young loblolly pine (Pinus taeda L.) plantations can be released from hardwood competition using dichlorprop as a directed-spray. Contract labor quality performance incentives have produced good hardwood control at costs somewhat higher than aerial spray costs. Spraying begins once leaves are fully expanded in spring and continues until early July. Difficult-to-control hardwoods can be killed if given thorough coverage early in the season. Pines will be damaged if sprayed accidentally.

INTRODUCTION

The suspension of forestry uses of 2,4,5-T left the Southeast United States without an effective herbicide for selectively releasing southern pine from hardwood competition. Approximately 240,000 ha of pine lands are being encroached upon annually by hardwoods in the Southeast (Walstad 1976). The search for herbicides to selectively control hardwoods on these areas at an acceptable cost continues with glyphosate, hexazinone and triclopyr receiving the most attention in current tests.

DEVELOPMENT

Weyerhaeuser has some 4,000 ha of loblolly pine plantations in Southwest Arkansas annually reaching the point where release is necessary. With no proven selective herbicide to use, foresters in this region began experimenting in 1979 with directed-spraying using backpack sprayers. This is not a new concept for southern pine release as even 2,4,5-T was applied in this manner on areas: (1) where drift would be a problem, (2) that were too small for economical aerial application, or (3) that were too steep for mist blower operation. In the 1979 tests, both Weedone^R 170, a 50:50 mixture of 2,4-D and 2,4-DP or dichlorprop, and Weedone^R 2,4-DP, dichlorprop only, were applied to hardwood brush in young loblolly pine plantation test plots. It soon became evident that Weedone 170 was producing considerably more pine damage than dichlorprop alone when inadvertently applied to pines, but hardwood control was essentially the same with both herbicides. The 2,4-D component of Weedone 170 probably was responsible for the increased pine damage. Areas sprayed with dichlorprop exhibited little pine damage unless the pines were sprayed deliberately.

Based on these results, Union Carbide obtained 24-C labels in Alabama, Arkansas and Mississippi to use dichlorprop as a directed-spray to control unwanted hardwoods in young pine plantations. During 1980 some 6,000 ha of pine plantations were treated on Weyerhaeuser lands in Arkansas. This paper reviews the techniques used in this directed-spray program and summarizes the results obtained as of early September, 1980.

PRESENT PROGRAM

The 1979 trials and the first weeks of the 1980 spray season clearly demonstrated the necessity of careful herbicide application to meet our goal of good hardwood control and minimal pine damage. Attention to quality control through each phase of the operation has given the desired level of brush control and the use of contract labor crews for application has allowed us to meet this goal at an acceptable cost.

Contractors are paid on a per-hectare basis with a quality incentive built into the payment schedule. Payment is made after herbicide symptoms begin to appear, i.e. one to two weeks after application. At that time, a Company inspector checks treated areas for: (1) coverage of assigned area, (2) coverage of brush less than 1.2 m tall, (3) coverage of brush greater than 1.2 m tall, and (4) pine damage. The contractor is paid a

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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percentage of the previously negotiated per-acre contract price based on the quality of work in each of these four categories. In 1980, contractor directed-spray application costs were approximately 50% higher per-hectare than the cost of aerial applications.

The Company provides the pre-mixed spray solution to the contractor at the plantation site to insure mixture uniformity. The mixture is prepared by adding one part of 480 g L^{-1} dichlorprop to 24 parts of water. A surfactant, Triton^{R} AG-98, is added at the rate of one part surfactant to 320 parts of the dichlorprop/water mixture.

Spraying begins once hardwood leaves are fully expanded in spring and continues until early July. As with many other foliage applied herbicides, dichlorprop efficacy decreases as the summer season progresses, hence the early July cut-off date.

In the field, the directed-spray crew typically consists of 10 people; each crew member owns the backpack type sprayer used. The crew members walk through the plantation abreast of one another spraying a 3 m wide swath of brush as they go. The laborers are instructed to spray to just short of the point of runoff. They are lead by the fastest working person and trailed by the slowest; the latter occasionally ties plastic flagging to mark the edge of the area just sprayed.

Directed-spray treatment is easiest when the hardwoods are small, i.e. less than 1.5 m tall. It is easier for workers to move through young plantations and thorough spray coverage of the competing stems can be accomplished quicker and with less herbicide than if larger trees are treated. Accidental spraying of pines also is reduced since nozzles usually are directed down over the tops of short competing stems. Pine growth also will be enhanced if they are essentially free-to-growth from an early age rather than being left until strong hardwood competition develops as was often done when releasing aerially with 2,4,5-T (Balmer et al. 1978, Langdon and Trousdell 1974, Roberts 1960). The value of these reportedly large growth gains far outweighs the somewhat higher cost of directed-spray treatment relative to aerial applications. Therefore, our directed spray program is aimed at two- to three-year-old pine plantations. Plantations that are going to have severe hardwood competition can be identified easily at this time.

RESULTS

Pines will be killed if sprayed thoroughly with the dichlorprop spray mixture. However, accidental contact with portions of the crown will kill only that portion of the foliage sprayed. Our assessments indicate that 40% of the pines exhibit some sign of herbicide contact, but this figure is understandable considering the intimate contact between hardwood and pine foliage in plantations in need of release. The level of damage on individual trees generally is not high.

Dichlorprop applied as a directed-spray has been effective in controlling most hardwood competition. Even red maple and ash can be controlled if given thorough coverage early in the spray season. A variety of plantations treated in the spring of 1980 were sampled in early September to assess the level of competition control. Only stems greater than one-half the height of nearby pines were included in the following summarization.

Species	Frequency %	Defoliation %
Sassafras (*Sassafras albidum*) (Nutt.) Nees	1	100
Persimmon (*Diospyros virginiana*) L.	1	97
Sumac (*Rhus spp.*) L.	21	94
Black-gum (*Nyssa sylvatica*) Marsh.	22	93
Hawthorn (*Crataegus spp.*) L.	1	85
Sweetgum (*Liquidambar stryraciflua*) L.	7	81
Black Cherry (*Prunus serotina*) Ehrh.	1	79
Elm (*Ulmus spp.*) L.	1	75
Red Oak (*Quercus spp.*) L.	11	70
White Oak (*Quercus spp.*) L.	8	69
Hophornbeam (*Ostrya virginiana*) [Mill.] K. Koch	1	68
Dogwood (*Cornus florida*) L.	9	57
Hickory (*Carya spp.*) Nutt.	11	45
Red Maple (*Acer rubrum*) L.	4	30
Ash (*Fraxinus spp.*) L.	1	10

SUMMARY

A directed-spray with a 4% dichlorprop solution plus surfactant gives good control of most hardwood brush competition in young pine plantations in Southwest Arkansas. In addition, monetary incentives to contract applicators for quality work has contributed to obtaining these results at a reasonable cost. Treating plantations at a young age before the hardwoods reach 1.5 m in height improves treatment efficacy, reduces accidental spraying of pines, reduces labor and material costs and leaves pines in a free-to-grow condition at an earlier age than if the treatment is delayed. This technique offers an alternative to aerial application of 2,4,5-T for pine release until an effective alternative aerial release herbicide treatment is available.

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DISCONTINUOUS MOUNDING AS A SITE TREATMENT ON A FLATWOODS SOIL[1]

James D. Haywood[2]

Abstract.--After four growing seasons, slash pines on treated plots (planted by hand on 38-cm and 75-cm high discontinuous mounds of topsoil formed by a crawler tractor on a very gently rolling Caddo-Messer silt loam complex) averaged 38 percent larger root-collar diameter and were 25 percent taller than pines planted on untreated plots. Slash pines grew equally well on both mound sizes. Discontinuous mounding did not hinder surface drainage, as continuous bedding on a very gently rolling silt loam soil often does.

INTRODUCTION

Bedding by conventional methods often only marginally increases height and volume growth in slash pine (*Pinus elliottii* Engelm. var. *elliotti*) plantations on flatwoods soils of the West Gulf Coastal Plain (Derr and Mann 1977, Cain 1978, and Haywood, In press). Pine survival is normally acceptable without planting on beds because most forested flatwoods of the West Gulf Coastal Plain are somewhat poorly drained rather than poorly drained (Derr and Mann 1977). Bedding improves local drainage, but the improvement can be nullified on very gently rolling silt loam soils because water stands in adjacent furrows at low points along the beds (Shoulders and Terry 1978). If average midwinter depth to free water exceeds about 45 cm on untreated sites, pine growth is acceptable without planting on beds (McKee and Shoulders 1970). On a very gently rolling silt loam flatwoods, the depth to free water may exceed 45 cm under pimple mounds, but be at the soil surface in intermound depressions.[3] So pine response to bedding on such sites may be highly variable. And planting on beds may increase the susceptibility of pines to fusiform rust (caused by *Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiforme* Burdsall and Snow), which can decrease survival (Haywood, in press).

Derr and Melder[4] informally tested discontinuous mounding on a Wrightsville (Typic Glossaqualf, fine, mixed, thermic) and Vidrine (Glossaquic Hapludalf, coarse-silty over clayey, mixed, thermic) silt loam complex to determine if artificial mounds would increase pine growth where the water table is at the soil surface in winter. After 6 years, slash pine survival was 6 percentage points higher on discontinuous mounds than on check plots.[3] Trees on discontinuous mounds averaged 56 percent larger d.b.h. (diameter at 1.37 m above groundline) and were 46 percent taller than slash pines on check plots, while slash pines on bedded plots averaged 17 percent larger d.b.h. and were 11 percent taller than trees on check plots. The early success of discontinuous mounding on this site led to further evaluations on a different very gently rolling flatwoods soil.

SOIL DESCRIPTION

The study area is located in central Louisiana on a Caddo (Typic Glossaqualf, fine-silty, siliceous, thermic) and Messer (Haplic Glossudalf, coarse-silty, siliceous, thermic) silt loam complex. The Messer silt loam is a deep, moderately well drained, slowly permeable soil developed from loam deposits. It occurs in the complex on convex circular mounds that are up to 21 m in diameter, and 75 cm in height. Size and frequency of mounds vary greatly but as many as 10 per hectare may be present. The Caddo silt loam is a poorly drained, slowly permeable soil

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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formed in deep loamy materials of nearly level terraces of mid to early Pleistocene age. The study area was divided into two topographic classes--an elevated flat of Caddo and Messer soils and a depression of Caddo soil. The depression forms a circular swale of about 0.4 ha and has very poor surface drainage.

VEGETATIVE COVER

The study area was kept relatively clean of shrubs and trees by periodic burning. But there were scattered clusters of southern bayberry (*Myrica cerifera* L.), post oak (*Quercus stellata* Wangenh.), and blackjack oak (*Q. marilandica* Muenchh.) on the Caddo-Messer flat, and a few isolated blackgums (*Nyssa sylvatica* Marsh. var. *Sylvatica*) in the swale.

Burning ended when the study was installed, and density of shrub and trees increased. After 4 years, topographic features could be distinguished by vegetative cover. Southern bayberry was very common on the elevated flat but lacking in the depression. Buttonbush (*Cephalanthus occidentalis* L.) was found only in the swale.

METHODS

After prescribed burning, rectangular, 15.25-m x 61-m plots were established in a randomized complete block design with two blocks in each topographic class. Two discontinuous mounding treatments and an untreated check were established in each block. Mounds were formed in late October 1975. In the first mounding treatment, a John Deere T350 crawler tractor equipped with a straight, 1.8-m wide dozer blade was used to push up piles of topsoil that averaged 38 cm high and had a 1.2-m x 1.8-m base. Mounds in the second treatment averaged 75 cm high. Within rows, mounds were spaced 6.1 m apart, center to center. Rows of mounds were spaced 3.05 m apart, center to center. Adjacent rows were offset in a staggered pattern. This arrangement allowed for 537 mounds per hectare. It took 11 hours to treat a single hectare.

After the mounds had settled, three uniformly graded slash pine seedlings were handplanted on each mound at 60 cm intervals in February 1976. Untreated check plots were planted at the same rate and spacing used on mounded plots. After the first growing season, one tree was rogued from each mound, or planting spot, if all trees survived. Criteria used in roguing were the presence of bole fusiform rust galls, spacing on the mounds, and seedling vigor.

Survival, bole fusiform rust infection, diameter at near groundline, and seedling height were measured at stand age 4. Survival and fusiform rust percentages were converted to arc sine √proportion before analysis. Individual tree data were averaged on a plot-by-plot basis. Using analyses of variance (0.05), I analyzed treatment effects separately by topographic class, and I pooled blocks to test for topographic differences and topography-treatment interaction. I used Duncan's Multiple Range Test to isolate differences between individual treatments.

RESULTS

At stand age 4, slash pine survival averaged 91 percent among rogued pines.

Occurrence of bole fusiform rust galls among surviving trees averaged 67 percent. Incidence of rust was similar on both topographic classes.

Percent survival and stem fusiform rust infection of slash pine after four growing seasons

Topographic class/ treatment	Survival	Trees infected with bole fusiform rust
	Percent	Percent
Caddo-Messer flat		
Check	86 a*	62 a
Low mound	94 a	63 a
High mound	90 a	75 a
Average	90	67
Caddo depression		
Check	92 a	66 a
Low mound	92 a	73 a
High mound	91 a	65 a
Average	92	68

* Means within each column followed by the same letter are not significantly different (0.05).

Discontinuous mounding improved the growth of slash pine, but size of mounds made no difference (table 1). Slash pines averaged 38 percent greater diameter and had 25 percent greater height per tree on mounds than did slash pine on check plots. Height growth during the fourth growing season was greater on mounds than on check plots. So pines on mounds were still growing faster than pines on check plots. Pines not infected with fusiform rust had similar results. Uninfected slash pines planted on mounds averaged 39 percent larger diameter, were 29 percent taller, and grew 37 percent more in height during the fourth growing season than did uninfected pines on check plots.

When treatments were averaged, tree diameter and height did not differ significantly between the Caddo-Messer flat and Caddo depression (table 1). All pines in the depression outgrew pines on the flat during the fourth growing season. But 4th-year height growth of uninfected pines did not differ between topography classes.

DISCUSSION

Had this soil complex been bedded instead of mounded, surface drainage from the depression and between the Messer mounds would have been blocked, and the impounded water would probably have limited pine diameter and height growth.[5] Discontinuous mounding did not restrict natural surface drainage. So growth was comparable over the entire tract, though the depression was a wetter site than the flat.

Height of mounds (38 cm vs 75 cm) was not important because slash pine can develop an adequate root system if the average midwinter depth to free water is about 45 cm. Providing depth beyond 45 cm for root growth has little added benefit. In fact, heights of mounds should be prescribed according to average winter depth to free water that is under distinguishable topographic classes. Such prescriptions may reduce per hectare costs. Pimple mounds, for example, probably drain deeply enough and would not need mounding. Flats between pimple mounds may or may not need mounded planting spots, depending on soil drainage. But depressions that are intermittent on the flats would need mounded planting spots for best diameter and height growth. And the mounds would have to be taller than the mounds formed on flats.

Continuous beds are less costly to form than discontinuous mounds. So using both bedding and discontinuous mounding on the same tract according to topographic conditions may be best. The same tractor used to pull the bedding plow could form the mounds. Surface features can be distinguished either after prescribed burning or by changes in vegetative cover. Beds, which are normally 25 cm tall from furrow to crest, could be confined to flats. Discontinuous mounds would be formed only in depressions, so surface runoff would not be restricted in the swales and the greater height of mounds (38 cm or taller) would help root development.

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Table 1.--Slash pine measurements at stand age 4

Topographic class/treatment	All surviving trees			Trees without bole fusiform rust cankers		
	Diameter	Total height	Height growth during 4th growing season	Diameter	Total height	Height growth during 4th growing season
	cm	m	m	cm	m	m
Caddo-Messer flat						
Check	3.58 a*	1.84 a	0.515 a	3.84 a	2.15 a	0.686 a
Low mound	4.95 b	2.25 cd	0.671 b	5.41 b	2.69 b	0.936 b
High mound	4.83 b	2.18 bc	0.677 b	5.21 b	2.64 b	0.972 b
Average	4.45	2.09	0.621	4.82	2.49	0.865
Caddo depression						
Check	3.86 a	1.96 ab	0.604 b	4.14 a	2.21 a	0.738 a
Low mound	5.31 b	2.56 d	0.747 c	5.66 b	2.99 b	1.012 b
High mound	5.46 b	2.51 cd	0.735 c	5.89 b	2.92 b	0.969 b
Average	4.88	2.34	0.695	5.23	2.71	0.906

* Means within each column followed by the same letter are not significantly different, Duncan's Multiple Range Test (0.05).

THE EFFECTS OF SITE PREPARATION ON GROWTH OF LOBLOLLY PINE IN SOUTHEASTERN LOUISIANA[1]

Shih-Chang Hu and Voradeth Ditthavong[2]

Abstract.--A study was made to determine the response of regular and genetically improved loblolly pine (Pinus taeda L.) seedlings to three different site preparations. Results at the end of the first growing season indicated that chopping plus burning was superior to chopping only and to intensive site preparation in terms of seedling survival and height growth.

INTRODUCTION

It is general knowledge that today's consumption of wood and wood products is increasing by leaps and bounds. Miller (1978) pointed out that the need for wood will far exceed the rates of production in the next 25 to 30 years. Moreover, the decrease of forest land is a chronic phenomenon here in the South, especially in Louisiana. This is due to a rapid expansion of urban and industrial zones. Another type of forest acreage loss stems from land clearing for uses that will provide a higher rate of return to the owner than that gained from forest activities (Marlin 1978).

Such circumstances generate the problem of accelerating wood production on decreasing forest areas. However, Haines et al. (1975) affirmed that future demands for timber could be satisfied if better forestry were utilized. To these authors, better forestry refers essentially to "successful regeneration and subsequent use of the full capabilities of the land." Haines et al. (1975) laid stress on the importance of site preparation, which is a prerequisite for forest renewal.

Although intensive site preparation -- chopping, disking, and ditching -- represents a popular practice in the South, many investigators have found that its need and desirability still remain in question. For intensive site preparation has not only proven to be expensive, it may deteriorate the site and jeopardize long-term forest productivity as well (May et al. 1973, Hebb and Burns 1975, Haines et al. 1975, Schultz 1975, Sundra and Lowry 1975, Moehring 1977).

The basic objective of this study was to determine the effects of site preparation on the growth of hand-planted loblolly pine (Pinus taeda L.), which is the most important timber species in the South. A subsidiary objective was to compare the rate of growth of regular seedlings with genetically improved seedlings.

METHODS AND PROCEDURES

Description of Experimental Area

This study was conducted on the LSU Idlewild Experiment Station near Clinton, Louisiana.

The average annual rainfall in this area is approximately 158 centimeters. The distribution of precipitation is fairly uniform throughout the growing season. The average temperature is 8.9°C for January and 26.7°C for July. The frost-free period averages about 247 days yearly.

The main forest type in Idlewild is pine or pine-hardwood with loblolly and shortleaf pines as dominant timber species. The site index for loblolly pine is about 100 in this experiment station.

Field Procedure

The plantations were hand-planted on recently clearcut sites in early February and March 1979. They consisted of three 0.80-hectare rectangular

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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blocks which received the following preplanting site treatments:

Treatment (Block) 1: chopped only;
Treatment (Block) 2: chopped and burned;
Treatment (Block) 3: chopped, burned, stumps removed, and double disked.

Each block was divided into two 0.40-hectare plots, one of which was hand-planted with 1-0 regular and the other with 1-0 genetically improved loblolly pine seedlings at 2.4 by 2.4-meter spacing respectively. Within each plot there were four replications consisting of 100 trees each, planted in 10 rows of 10 trees each (a 0.06-hectare subplot). Thus there were a total of 24 measurement subplots. To minimize border effects, a strip of 4.8 meters wide was established around each subplot.

The planting stocks were obtained from the Louisiana Office of Forestry's nursery in DeRidder, Louisiana. The genetically improved and regular seedlings were treated the same in the nursery. The improved seedlings came from seed collected from an open-pollinated, unrogued seed orchard.

The initial height of each seedling was measured in April 1979, before height growth began. The height growth and survival rate at the end of the first growing season was made in January 1980.

Statistical Analysis

Paired t-tests were used to test the significance of difference between the average height growths and survival rates of the regular and genetically improved seedlings planted on each treatment or block.

Comparisons of the average height growths of the seedlings between treatments or blocks were made by a least squares analysis of variance using a t-test.

RESULTS AND DISCUSSION

Survival and Treatment

The average survivals for each of the three treatments are presented in Table 1. It appears that the best survival (86.5 percent) occurred on chopped and burned plots, and the lowest (71.4 percent) on the most intensively treated plots (Treatment 3). The treatment which involved only chopping had an intermediate rate of survival (77.8 percent). The results noted in this study are in contrast to the observations made by Wells and Crutchfield (1974). The two investigators found that the more intensive the treatment (clearing with a KG blade plus windrowing plus double disking), the greater the survival.

The cause of low survival in treatment 3 may be because the seedlings were planted too soon after disking. It has been reported that planting on freshly disked soil can result in 40 to 50 percent mortality in the first or second month even if the soil is moist (Mann 1974).

The best survival in treatment 2 was probably due to beneficial effects provided by chopping and burning. McNab and Ach (1977) remarked that one year after planting loblolly pine seedlings planted in ashes of burned logging slash had five times greater survival than those planted away from the ashes.

The difference in survival between treatment 1 and treatment 3 (77.8 percent versus 71.4), though not substantial, may illustrate the adverse effect of soil disturbance which reduced productivity of the site.

Survival and Type of Planting Stock

At each level of site preparation, the survival of regular trees was greater than that of genetically improved trees (Table 1). The range in average survival was from 78 to 91 percent for ordinary planting stock and from 65 to 82 percent for superior material.

Both varieties of loblolly pine survived best on treatment 2 (Block 2), second best on treatment 1 (Block 1), and less on treatment 3 (Block 3).

There is a statistically significant difference in favor of regular seedlings at the 5 percent level of probability. On the average, the regular seedlings had a survival rate of 83.7 compared to only 73.7 percent for genetically improved seedlings.

These results, however, do not support the evidence provided by Dutrow and Row (1976), in which the survival of superior seedlings was greater than that of regular seedlings.

On the basis of this study, inappropriate environment and conditions were perhaps the main cause of the inferior performance of genetically improved trees. According to Goddard et al. (1975), the best genetic stock never produces its full potential if soils having critical nutrient deficiencies are not fertilized.

Height Growth and Treatment

The average height growths of loblolly pine at the end of the first growing season are shown in Table 1 and illustrated in figure 1. The best height (28.95 centimeters) was found in plots which were chopped and burned, and the lowest (20.06 centimeters) in chopped, stumps removed, and double disked plots. The trees that received chopping only had an intermediate height growth (22.35 centimeters).

Table 1.--Relationship of site preparation treatment and seed origin to first-year survival and height increment of 1-0 loblolly pine seedlings

Site preparation treatment	Regular		Genetically improved		Average	
	Surv.	Ht. inc.	Surv.	Ht. inc.	Surv.	Ht. inc.
	Percent	Cm	Percent	Cm	Percent	Cm
Chopped	82.0	23.1	73.5	21.6	77.8	22.35
Chopped, burned	90.8	33.0	82.3	24.6	86.5	28.95
Chopped, burned, stumps removed, and double disked	78.0	21.1	64.8	17.8	71.4	20.06
Average, 3 treatments	83.7	25.7	73.7	21.7	78.6	23.7

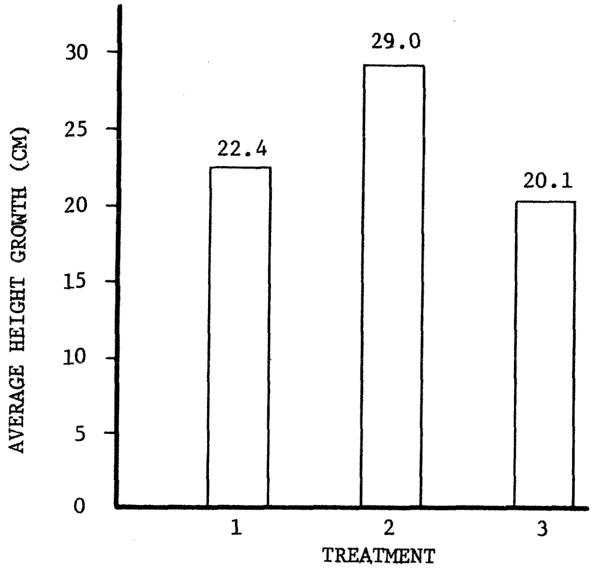

Figure 1.--Average first-year height growth of loblolly pine grown on three differently prepared sites.

Trees on treatment 2 (chopped and burned) averaged 8.89 centimeters (44.3 percent) and 6.60 centimeters (29.5 percent), respectively, taller than those on treatment 3 and treatment 1. The average height of trees grown on treatment 1 (chopped only) was 2.29 centimeters (11.4 percent) greater than that of those on treatment 3. The comparisons of the average height growths of loblolly pine seedlings indicated that the differences were statistically significant at the 1 percent level of probability.

As with the case of survival, the results obtained for average height growth in this study were also in contrast with the findings revealed by Wells and Crutchfield (1974) and Hunt and Cleveland (1978), in which the tree heights increased with the intensity of site preparation.

On the basis of the present investigation, it is difficult to know exactly what factors affected the height growth of the seedlings. But, the beneficial effect created by burning of logging slash and less intense competition from ground cover vegetation appeared to be one of the probable causes of the improved height growth in treatment 2. McNab and Ach (1977) reported that, at age one, the average height growth of seedlings planted in ashes of burned logging slash was more than twice that of seedlings not in the ashes. Lennartz and McMinn (1973) noted that increases in height growth were related to the degree of disturbance or reduction of competing vegetation.

The poorer height growth in treatment 3 was possibly due to the fact that topsoil was removed or disturbed during the operations of site preparation.

Height Growth and Type of Planting Stock

Figure 2 shows a histogram of average height growths of regular and genetically improved loblolly pine seedlings planted on three differently prepared sites.

Obviously, both kinds of planting stock grew best on treatment 2, second best on treatment 1, and poorest on treatment 3. The range in average height growth was from 21.1 to 33.0 centimeters for regular seedlings and from 17.8 to 24.6 centimeters for genetically improved seedlings.

The regular seedlings on treatment 2 averaged 9.9 (42.8 percent) and 11.9 centimeters (56.4 percent) greater in average height growth than those on treatment 1 and treatment 3.

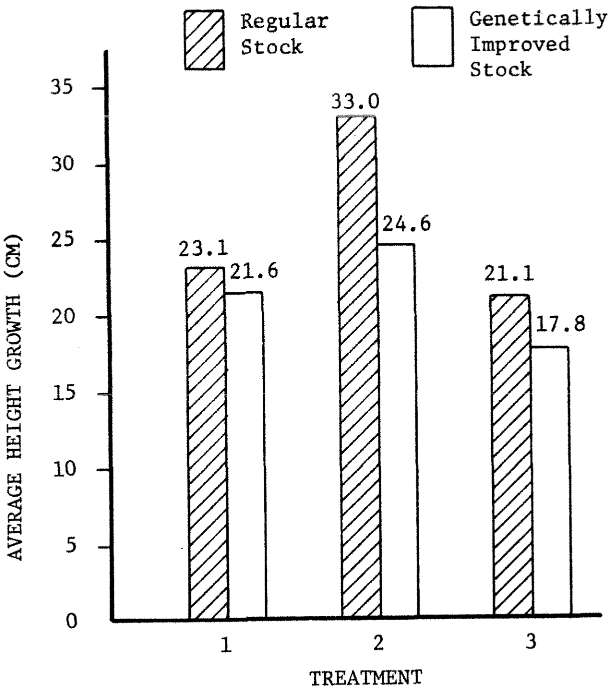

Figure 2.--Average first-year height growth of regular and genetically improved loblolly pine.

Treatment 1, however, produced 2.0 centimeters (9.5%) more average height growth than treatment 3.

The average height growth of genetically improved seedlings in treatment 2 was 3.0 centimeters (13.8 percent) and 6.8 centimeters (38.2 percent) greater than that of the seedlings in treatment 1 and treatment 3 respectively. On treatment 1 the genetically improved trees averaged 3.8 centimeters (21.3 percent) taller than those on treatment 3.

The regular trees on treatments 1, 2, and 3 averaged, respectively, 1.5 centimeters (6.9 percent), 8.4 centimeters (34.1 percent), and 3.3 centimeters (18.5 percent) greater in height growth than the genetically improved trees.

Although the regular trees outgrew the genetically improved trees on every treatment, no significant differences were detected between the average height growth of the two varieties of loblolly pine when all three site preparation treatments were combined in the analysis.

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EFFECT OF MECHANICAL SITE PREPARATION TREATMENTS ON HEIGHT GROWTH OF LOBLOLLY PINE IN EAST TEXAS SANDY SOILS[1]

Steven J. Arbour and Andrew W. Ezell[2]

Abstract.--The effect of using chop/burn versus shear/windrow/burn site preparation in the sandy soils of East Texas was evaluated by comparing total tree heights of ten-year-old loblolly pine (Pinus taeda L.) plantations. Stem analysis was completed on 120 trees to reconstruct height growth patterns. Results from the study indicate that trees performed better on sites receiving a chop/burn treatment when the overall site/treatment interaction is considered.

INTRODUCTION

In view of the concurrent trends of increasing demand for forest products and decreasing availability of commercial forest land, forest land managers are confronted with the prospect of producing more on less land. The obvious solution to this problem resides in increased intensive management of forest lands. In the South, this directive often leads to intensive cultural manipulation of even-aged stands of pine created by harvest-regeneration activity involving clearcutting and planting.

Following harvest operations, the first problem to be resolved in intensive pine management is the disposition of undesirable debris and residual vegetation. There are approximately 138 million acres in the South classed as southern pine sites. Of this total, alomost 73 million acres support varying amounts of unwanted hardwoods, and recent estimates indicated nearly 0.8 cubic feet of hardwoods for every cubic foot of pine on these sites (Murphy and Knight 1974).

To alleviate the problem of debris and residual vegetation, site preparation activities are usually undertaken and may be either mechanical treatments, chemical applications, burning or some combination of the three. Mechanical treatments (usually in conjunction with fire) are the prevalant form of site preparation activities in Texas, accounting for an estimated 70 per cent of the annual site preparation acreage (Blackburn et al. 1978).

Chopping and shearing are two mechanical treatments commonly employed on the sandy soils of the Coastal Plain region of East Texas. Chopping with burning is the preferred method on these sandy soils since it reduces unwanted vegetation with less soil disturbance (Balmer and Little 1978, Balmer et al. 1976, Grelen 1959).

Shearing and windrowing is very effective in concentrating debris and residuals but may result in scalping the soil surface. This site preparation method is used extensively on coarse-textured soils even though it may displace an appreciable amount of topsoil and possibly reduce site productivity (Burns and Hebb 1972, Brendemuehl 1967, Haines et al. 1973).

Quantitative information relating tree height growth performance to chopping or shearing is lacking for East Texas. Such information is valuable to land managers in deciding which method or combination of methods has a more favorable effect on yield. Therefore, it is the purpose of this paper to examine height growth of loblolly pine in relation to mechanical site preparation treatments conducted on the sandy soils of East Texas.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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The research was completed while Mr. Arbour was a graduate research assistant at Texas A&M University, College Station, TX 77843.

MATERIALS AND METHODS

Ten-year-old loblolly pine plantations located within the Willis Geologic formation of the Upper Coastal Plain region were used as sample sites in this study. Selection of plantations was according to the following criteria: (1) plantations to be ten years of age, (2) planting stock of similar grade, (3) survival rate of at least 60 per cent, (4) no severe evidence of fire, insect, or disease damage, and (5) plantation received its site preparation treatment during summer or fall of 1969.

Plantations chosen had received either chop/burn or shear/windrow/burn site preparation, and all had been machine planted during the 1969-70 planting season. A total of four plantations (hereafter referred to as locations) were selected.

For the study, a total of twenty (20), two-acre study sites were delineated. Each site was marked as a square block with sides 295 feet long. Within each study site, three (3) circular 1/20-acre sample plots were established, resulting in a total of 60 sample plots for the study. All planted trees within each sample plot were numbered with aluminum tree tags to facilitate data collection and future identification.

In addition to other data collected from each plot, two trees were selected for stem analysis to evaluate height growth. Trees with excessive crook, sweep, or forked growth were not considered for selection and total of 120 trees were felled for stem analysis data. Discs, approximately one inch wide were removed at four-foot intervals starting at the base of the tree and proceeding to the top. All sample discs were tagged to ensure proper identification.

The annual height growth pattern for each tree was reconstructed using the method developed by Curtis (1964). Lenhardt's (1974) adjustment technique was employed to correct for growth peaks located between sample discs. From the data collected, annual total height and mean annual increment were determined.

RESULTS AND DISCUSSION

Evaluation of height growth between chop/burn and shear/windrow/burn site preparation treatments discloses that average total tree height is higher on sites receiving a chop and burn site preparation treatment (Table 1.). Trees growing on the chop and burn areas averaged 7 per cent taller in total height than trees found on shear, windrow and burn sites. However, treatment effect accounts for only part of the variation associated with height differences. The stratified/nested sampling design used in the study requires an analysis of treatment/location interaction to account for height differences between treatments and among locations.

Table 1. Average Annual Tree Height by Treatment and Location

Tree Age	Chop/Burn Plantation 1	Chop/Burn Plantation 2	Shear/Windrow/Burn Plantation 3	Shear/Windrow/Burn Plantation 4
-yrs-	-----ft------	-----ft-----	-----ft-----	------ft-----
1	2.0	1.6	1.4	1.6
2	5.4	4.6	3.8	5.0
3	10.2	8.1	8.1	9.3
4	14.6	11.6	12.2	13.5
5	19.2	14.6	16.2	16.6
6	23.6	18.8	20.1	20.1
7	27.3	23.3	24.4	23.0
8	31.0	26.6	27.8	26.1
9	34.4	29.3	30.8	28.9
10	37.3	32.2	33.3	31.4
11	40.1	35.1	35.8	33.9

Height differences which may be attributed to the treatment/site interactions are analyzed in Table 2. Results of the test indicate that average total tree heights differ among locations at the $P < .01$ level.

Table 2. Analysis of variance on the effect of treatment and location on tree height.

Source	df	ss	ms	f
Location x Treatment	3	121.87	40.62	9.74**
Variation Within (Loc. x Trt.)	16	66.72	4.17	
Total	19	188.59		

**significant at $P < .01$

Average annual total height trends associated with each location are found in Figure 1. The average height of trees growing on Location 1 was 12.5%, 10.7%, and 15.5% greater than trees on Locations 2, 3, and 4, respectively. It should be noted that trees growing at Location 1 maintained height dominance over the other locations throughout all ten growing seasons.

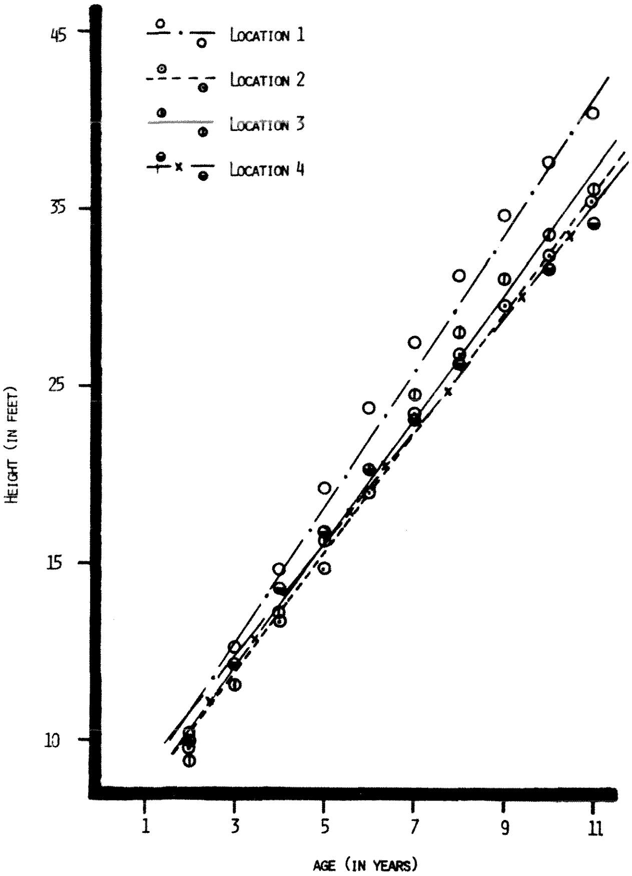

Figure 1. Average annual total height for all locations

Trees on Locations 2, 3, and 4 share a closer trend in height growth. Trees on Location 4 exhibited greater height growth than trees on Location 2 and 3 during the first four growing seasons. At this point, average tree height on Location 3 surpassed that found on Location 4 and remained greater through the tenth growing season. Average tree height on Location 2 surpassed that found on Location 4 after the seventh growing season. This variation in height dominance among the locations suggests a change in the overall capacity of the planted trees for utilizing the resources of the site and that site potential is being reflected in height growth during the later years examined in this study.

Since we are dealing with a cultural treatment applied to a physical site, consideration must be given not only to the two variables but to the site/treatment interaction as well. Variation in height growth patterns found among the locations may be due to a response to site preparation activities, differences in soil properties, or products arising from the interaction such as vegetative competition levels.

While it is beyond the scope of this paper to fully examine the effect of physical site properties, various soil parameters were measured and evaluated. Overall, Locations 1 and 2 are comparable in soil physical properties, and Locations 3 and 4 were quite similar in their measured soil characteristics. Thus, height differences due to site preparation effects may be examined within comparable soil regimes.

The greater soil depths to the least permeable horizon found at Locations 1 and 2 offer an increased volume of soil available for root penetration. Pentration and extension of root systems is a critical factor in tree growth on sandy soils. The significant differences in average total height observed between Locations 1 and 2 may be attributed to other site variable-i.e. nutrient pool (as evidenced by the density of vegetation supported by two sites), soil moisture regime, or orographic differences.

By comparison, soils found at Locations 3 and 4 were considerably shallower and of finer texture than the soils at Locations 1 and 2. Root development was probably more variable and of lesser extent on these shallower sites. As was the case with Location 1 and 2, variation in height between Locations 3 and 4 was due to other inherent site properties.

In relating height growth patterns to soil physical properties, it appears plausible that trees on Location 4 encountered adverse root development conditions around age 4 due to the shallower, finer-textured soils. Height growth was restricted on Location 3 during the initial establishment period, but accelerated after the trees adapted to local site conditions. The trees on Location 2 encountered fewer impediments to root development, and although repressed in the early years, were able to better utilize the sites resources in the later years of growth examined.

In order to examine variation in height growth patterns for all locations, the annual per cent differences in tree height were evaluated (Figure 2). Location 1, the best site in terms of height growth, was used as a base, and all other locations were compared to values from that site. This comparison reveals a leveling trend in height differences past the sixth growing season. Height differences peaked at year four between trees of Locations 1 and 2.

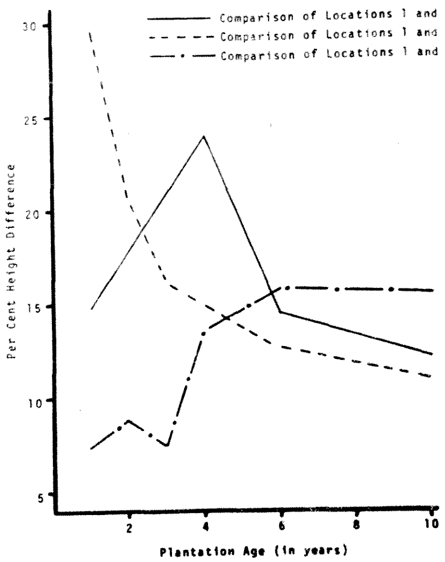

Figure 2. Comparison of differences in average annual total height for all locations.

Height trend between Locations 1 and 3 follow a different path, with per cent height differences declining until the sixth growing season, whereafter, the per cent differneces level out. The greatest differences in height growth patterns existed between Locations 1 and 4. Per cent height differences peak at year six, with tree heights maintaining a uniform difference in growth rates through year ten. Again, in each of the above comparisons, height dominance seems to be expressed by the sixth growing season, with differences in per cent tree height leveling out and being maintained through the tenth growing season.

The results obtained from the study indicate that height growth was better on sites receiving a chop/burn site preparation treatment. Though differences in soil properties exist among the locations, the study was geared to evaluate mechanical site preparation activities employed in the sandhill region of East Texas. Since each location received soil scarification during the planting operation, it would seem best to implement a chop/burn site preparation treatment in order to incorporate and conserve available nutrients on the site. Implementing shear and windrow practices could possibly give a double-scarification effect to the site, augmenting removal of the nutrient-enriched top soil in these sandy soils and, also, exposing more of the soil to temperature extremes and erosive forces. These sandy soils represent an extreme of the total spectrum of forest sites found in East Texas, and the impact of site preparation activities during the critical early years of plantation establishment may be more pronounced on these sites. Thus, proper selection have substantial effects on the height growth of planted trees in these areas.

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THINNING AND FERTILIZATION OF LOBLOLLY PINE PLANTATIONS[1]

R. Ballard, H. W. Duzan, Jr. and M. B. Kane[2]

Abstract.--Gross volume response to nitrogen fertilization in 12 loblolly pine plantations averaged 197 and 157 cu.ft/acre over a 4-year period for thinned and unthinned areas, respectively. When assessed in terms of net volume, sawlog volume and mean diameter the relative fertilizer response advantage in thinned stands was more pronounced and consistent than for gross volume. Periodic volume response to both thinning and fertilization is modelled in terms of stand and site variables.

INTRODUCTION

Thinning and nitrogen fertilization of loblolly pine are increasingly being looked to as means of increasing yields and reducing the time for trees to grow to merchantable sizes. In addition to the opportunities provided by these silvicultural practices for alleviating supply problems created by an imbalance in age and size classes (Zobel 1980), thinning in particular is gaining in popularity for generating cash flow on small private ownerships and as a cultural practice designed to reduce the risk of southern pine beetle damage (Ku, _et al_ 1980).

The evaluation of management alternatives and the prescription of economically and silviculturally sound management practices requires the availability of models which accurately predict the effect of various management regimes on yield for a range of conditions. The development of such models, particularly for thinning and fertilization effects, has been hindered by a lack of suitable data sets for constructing or validating such models and a limited understanding of variables influencing tree and stand response to management practices.

This paper presents some preliminary results from a series of thinning x N fertilization studies installed in loblolly pine plantations by Forest Industry Cooperators of the North Carolina State Forest Fertilization Cooperative (NCSFFC). Because of the preliminary nature of the data they are examined more with the intent of improving our understanding of the nature of the response to thinning and fertilization rather than for construction of predictive models.

METHODS

Trial Description

The basic study consists of a 2 x 2 factorial of thinning (+ -) and N fertilization (+ -) arranged in a randomized block design. The treatments were replicated four times at each site. The same basic study was installed at 19 separate sites. The 12 studies for which we have 4-year measurements are reported in this paper. The site and stand characteristics at time of study establishment at each of these 12 sites are given in table 1.

The thinning prescription was to reduce the basal area (sq.ft/acre) to the numerical equivalent of the estimated fifty-year site index by selective thinning from below. While the thinning prescription was consistent within sites, it was rather loosely interpreted by most cooperators giving a range of thinning intensities over sites (table 1).

Nitrogen fertilizer was applied in early spring as ammonium nitrate at the rate of 150 lbs N/acre. On sites where P or K deficiencies were suspected, on the basis of soil and foliar analysis, fertilizer applications of these elements were made to all plots.

Measurements

Diameter at breast height and heights of all or a sample of trees across the diameter range

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Table 1.--Initial site and stand characteristics

Study No.[1]	Age	Site index[2]	Stems per acre UT[3]	Stems per acre T	Basal area UT	Basal area T	Mean diameter UT	Mean diameter T
(yr)	(ft)				--(sq.ft/ac)--		----(in)-----	
2	16	61	555	311	101	92	6.4	7.3
[illegible]	15	[illegible]	601	402	145	120	6.5	7.1
11.1	14	60	619	409	97	80	5.1	5.8
11.2	12	79	540	285	150	99	7.0	7.9
14	17	53	660	308	164	103	6.5	7.8
15.1	11	67	568	250	173	91	7.3	8.1
15.2	15	72	600	254	179	92	7.3	8.1
[illegible]	14	64	719	319	166	100	6.4	7.5
16	12	76	762	415	191	116	6.7	7.1
22.1	20	66	446	208	158	83	7.9	9.1
22/3	20	56	470	248	161	101	7.9	8.6
23	15	61	717	303	131	84	6.1	7.1

1/ NCSFFC Study code.
2/ 25 year base
3/ Unthinned (UT), thinned (T)

were recorded at the initiation of the trials and again after four growing seasons. Heights for all trees in each plot were estimated from height-diameter equations developed for each treatment.

Total individual tree stem volumes (o.b.) were calculated using the volume equation of Smalley and Bower (1968). Net periodic volume increment was obtained by taking the difference between estimates of per acre living volume at trial initiation and that after four growing seasons. Gross periodic volume increment was obtained in a similar manner except trees which died during the 4-year assessment period were included in the estimate of the volume at the end of the assessment period. Sawlog volumes were calculated using the equation of Burkhart et al. (1972).

Statistical Analysis

Estimates of volume and diameter increments over the 4-year measurement period were adjusted for initial differences in these variables using covariance analysis. The covariance adjustment was done within thinning treatment as it would otherwise remove thinning effects since the covariate is related to thinning.

RESULTS AND DISCUSSION

Thinning Response (unfertilized stands)

Thinning in unfertilized stands reduced 4-year gross volume increments an average of 322 cu.ft/acre (21.8%) over that in unthinned plots (table 2). However, as a result of a lower mortality in thinned plots, the average reduction was only 9.6% for net volume increment and 5 out of 12 trials even showed a gain in net volume production in the thinned relative to the unthinned treatments.

As expected, mean diameter increment in thinned stands was greater than that in unthinned stands due to concentration of growth on fewer stems. Despite this concentration of growth on fewer, larger stems in thinned stands, sawlog volume increment was on average still greater in unthinned stands. Undoubtedly most of the volume increment in the unthinned stands was put onto dominant and codominant stems; the lack of growth on small suppressed trees would act to reduce the average diameter increment in unthinned stands.

The trends noted above are not unusual or new (Feduccia and Mann 1976). They are also obtained over a relatively short growth period and since thinning effects tend to be long-term in nature, they must be regarded only as early trends.

Growth in Thinned Stands (unfertilized)

To gain an insight into factors influencing growth of thinned stands, two approaches are available: develop an independent model of growth for thinned stands or examine deviation in growth in thinned stands from those predicted using a standard growth model for unthinned stands. We chose the latter approach because of the availability of an independent model for predicting periodic volume increment of loblolly pine stands and the general acceptance of the philosophy of this approach in modelling management effects on forest yields (Pienaar 1979; Reukema and Bruce 1977).

The independent model relating 5-year gross volume increment (PV5) to basal area (BA) and 25-year site index (SI) was developed with data from 79 NCSFFC study sites representing close to the complete ranges of site and stand conditions found in unthinned, unfertilized loblolly pine plantations in the South:

$$PV5 = (9.7 + BA)/(0.046 - 0.0004*SI + 0.0008*BA - 0.000005*BA*SI)$$

$$R^2 = 0.66 \qquad Sx.y = 287$$

Using this model PV5 was predicted for each of the 12 thinned and unthinned stands. To enable comparison with the observed 4-year gross volume increment, predicted PV5 was proportionally adjusted using a factor of 0.8. Deviations between observed and predicted values were calculated as were the standard deviations of these residuals for each type of stand:

Stand	4-yr gross volume increment Mean Observed	Predicted	Residual	Sx.y Residual
	--------(cu.ft/acre)---------			
Unthinned	1478	1427	25	268
Thinned	1156	1319	-188	313

There is a good prediction of volume increment in the 12 unthinned stands with a close correspondence of Sx.y values for the independent model using the original 79 sites and the 12 current study,

Table 2.--Four-year volume and diameter increments for unthinned (UT) and thinned (T) stands

Study No.	Gross volume			Net volume			Sawlog volume			Mean diameter 1/	
	UT	T	(UT-T)	UT	T	(UT-T)	UT	T	(UT-T)	UT	T
	(cu.ft/ac)						(bd.ft/ac)			(in)	
2	1132	1044	*88*	733	1042	*-309*	3532	3691	*-159*	0.72	0.87
9	1599	1713	*-114*	1428	1623	*-195*	5930	6432	*-502*	0.64	0.88
11/1 2/	1492	1359	*133*	1392	1298	*94*	3678	3390	*288*	0.89	1.00
11/2	1742	1305	*437*	1729	1305	*424*	6131	4873	*1258*	0.60	0.83
14	1070	914	*156*	862	886	*-24*	3410	3531	*-121*	0.41	0.74
15/1	1215	787	*428*	580	739	*-159*	4675	3068	*1607*	0.38	0.59
15/2	1483	753	*730*	885	379	*506*	5310	2444	*2866*	0.39	0.60
15/3	1690	1383	*307*	1505	1265	*240*	5421	5195	*226*	0.63	1.22
16	1936	1349	*587*	1498	1300	*198*	6888	4829	*2059*	0.57	0.80
22/1	1208	894	*314*	750	793	*-43*	4426	3231	*1195*	0.51	0.84
22/5	1224	904	*320*	1122	904	*218*	4547	3758	*789*	0.60	0.73
23	1947	1471	*476*	1880	1445	*435*	4998	5306	*-308*	0.74	1.39
Avg.	1478	1156	*322*	1197	1082	*115*	4912	4144	*768*	0.59	0.87

1/ Mean increment on trees surviving at the final measurement.
2/ Five-year data.

unthinned sites. This provides confidence that the large deviation between observed and predicted values for thinned stands, shown above, is a real effect of thinning and not the result of the 12 sites representing a different population from that used to construct the independent model.

Our data above show that volume growth in thinned stands is, on average, well below that in unthinned stands of the same basal area and site index. We hypothesized that deviations from predictions using unthinned stands might be associated with effects of thinning on 1) the crown/basal area ratio, 2) the diameter distribution, and 3) damage to the soil and residual trees. A number of variables, with potential as indicators of effects 1) and 2) were screened for their ability to explain variation in the deviations from predicted volume increment (RES. V). We had no measure of thinning "damage" for the various sites. Variables screened included:

$$\text{Relative basal area reduction (BAR)} = \frac{BAU - BAT}{BAU},$$

Where BAU = basal area for unthinned stand
BAT = basal area for thinned stand,

$$\text{Index of selectivity (IS)} = \frac{\log\ (BAR)}{\log\ (SPAU-SPAT/SPAU)},$$

Where SPAU = stems/ac for unthinned stands
SPAT = stems/ac for thinned stands
(note, the more selective the thinning is for size-low thinning-the larger IS becomes-Pienaar 1979),

and also BAU, BAT, SPAU, SPAT, BAU*SPAU and SI.

The best single, double and triple variable prediction equations developed, after looking at all variable combinations, are shown below:

1. $RES.V = -1765 + 1107{*}IS \quad R^2 = 0.33 \quad Sx.y = 268$

—the more selective the thinning (from below) the less the reduction in volume growth relative to an unthinned stand of the same BA & SI.

2. $RES.V = -1842 + 766{*}IS + 1.82{*}SPAT \quad R^2 = 0.46 \quad Sx.y = 256$

—the more selective the thinning and the larger the number of stems left after thinning, the less the reduction in volume growth relative to an unthinned stand of the same BA and SI.

3. $RES.V = -766 + 11.5\ BAT - 8.3\ BAU + 1.25\ SPAU \quad R^2 = 0.52 \quad Sx.y = 253$

—the greater the basal area left after thinning, the greater the number of stems before thinning and the lower the basal area before thinning, the less the reduction in volume growth relative to an unthinned stand of the same BA and SI.

Little effort will be made here to develop biological explanations for the above relationships It is apparent that most of the variables are in some way related to the selectivity of thinning, the intensity of thinning, and the degree of suppression of residual tree crowns. Suffice it to say that these relationships provide an indication of the types of variables we should evaluate in attempting to develop definitive thinning models. A word of warning however, the relative importance of different variables in predicting deviations in periodic growth of thinned stands will undoubtedly vary according to the length of the period after thinning considered.

The generally low R^2 values for our "best" prediction equations indicate that we have a long way to go in developing appropriate variables to account for the effects of thinning. One effect not evaluated here, and which may account for some of the unexplained variation, is the effect of damage to the soil and residual trees during the thinning operation. Work is needed on this important question.

Fertilizer Response

Volume and diameter responses to fertilization were significant in 9 out of the 12 trials. The magnitude and frequency of the response to N fertilizer is consistent with the findings of NCSFFC from a large number of other trials in loblolly pine plantations (Ballard 1980). Gross volume responses were, on average, greater in thinned stands, but it was not a consistent trend (Table 3). While the average relative response gain for thinned over unthinned stands was only 25% for gross volume, it was 49%, 64%, and 90% for net volume, sawlog volume, and mean diameter, respectively. The consistency of the trend also increased in the same order. Such a trend is expected with the volume response in thinned stands goint onto fewer, larger stems (fig. 1). Volume response in thinned stands thus tends to

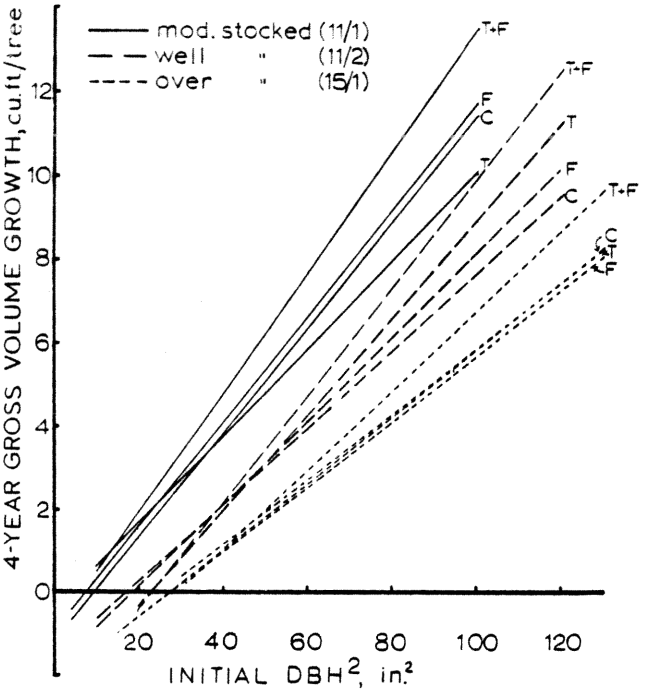

Figure 1.--The effect of thinning (T) and fertilization (F) on volume growth by initial diameter class in three loblolly pine stands of different initial stocking.

Table 3.--Four-year volume and diameter gains from N fertilization of unthinned (UT) and thinned (T) stands.

Study No.	Gross volume			Net volume			Sawlog volume			Mean diameter[1]		
	UT	T	(UT-T)	UT	T	(UT-T)	UT	T	(UT-T)	UT	T	(UT-T)
	(cu.ft/ac)						(bd.ft/ac)			(in)		
2	166	2	*164*	255	-60	*310*	159	-107	*266*	0.06	0.13	*-0.07*
9	173	96	*77*	45	32	*12*	43	270	*-227*	0.08	0.13	*-0.05*
11/1[2]	163	348	*-185*	127	385	*-258*	-149	1052	*-1201*	0.03	0.36	*-0.03*
11/2	-44	201	*-245*	-193	201	*-394*	-90	1073	*-1163*	0.08	0.18	*-0.10*
14	404	241	*163*	373	269	*104*	1249	1019	*230*	0.13	0.16	*-0.03*
15/1	84	135	*-51*	84	69	*15*	109	418	*-309*	0.05	0.13	*-0.08*
15/2	139	313	*-174*	675	434	*241*	832	1245	*-413*	0.21	0.27	*-0.06*
15/3	216	199	*17*	-13	169	*-182*	350	723	*-373*	0.16	0.07	*0.09*
16	103	342	*-239*	-35	345	*-380*	578	1336	*-758*	0.10	0.22	*-0.12*
22/1	133	107	*26*	-183	-20	*-163*	-19	393	*-413*	0.15	0.10	*0.05*
22/5	185	112	*73*	217	98	*119*	859	127	*732*	0.06	0.27	*-0.21*
23	157	260	*-103*	135	286	*-151*	872	303	*569*	0.05	0.20	*-0.15*
Avg.	157	197	*-40*	124	185	*-61*	399	654	*-255*	0.10	0.19	*-0.09*

[1] Mean gain on trees surviving at the final measurement.
[2] Five-year data.

be more valuable than an equivalent response in unthinned stands.

An often heard concern about thinning is the effect it has over conventional rotation lengths, of reducing total volume yield. Our data show that fertilization can be used to offset this yield loss. Over the 4-year period from thinning, thinned and unfertilized stands produced 322 and 115 cu. ft/acre less gross and net volume, respectively, than their unthinned counterparts (table 2). Fertilization of thinned stands however increased gross and net volume production 197 and 185 cu. ft/acre, respectively (table 3). Thus thinned and fertilized stands had a greater net volume production (70 cu.ft/acre) but a still lower gross volume production (-125 cu.ft/acre) than unthinned stands over the 4-year period. Fertilization acts to speed up site reoccupancy after thinning.

Modelling Fertilizer Response

Unthinned stands — Consistent with our findings using data from other trials (Duzan and Allen 1980) we found a simple model with basal area at time of fertilization (BA, sq.ft/acre) and site index 25 (SI, ft) gave the best prediction of 4-year gross volume response to N fertilization (ΔV, cu.ft/acre)

$$\Delta V = 736.8 + 1.55 * BA - 12.6 * SI \qquad R^2 = 0.63 \quad sx.y = 68.3$$

The 12 plantations used for these studies are on non P-deficient sites with a relatively narrow range of drainage classes. Under these circumstances the SI may be reflecting site N status. Basal area, as an index of growing stock, reflects the potential of the stand to put on extra volume in response to fertilization.

Thinned stands--In addition to SI and BA a number of other variables including IS, BAR, SPA were screened alone and in various combinations for predicting gross volume response in thinned stands. The general level of prediction was very poor with only one variable (stems per acre prior to thinning, SPAU) providing a significant prediction.

$$\Delta V = -214 + 0.68 * SPAU \qquad R^2 = 0.38 \quad Sx.y = 90.1$$

The R^2 value for the equation could not be significantly improved by inclusion of any other tested variable. The biological explanation for this relationship is unclear and thus use of it for prediction purposes, even within the range of conditions encountered in the calibration population, is not recommended.

Our understanding of the mechanism of N fertilizer response in thinned stands must be improved in order to generate variables with a sound biological basis and good predictive capability. A factor which could have contributed to the poor prediction by site and stand variables is a variation between sites in degree of site disturbance during thinning. The degree of disturbance can influence both the N status of the site and the vigor of the residual trees.

It is noticeable that while the characteristics of thinning response and fertilizer response in unthinned stands are influenced by stand conditions, those of response in thinned stands appear to be largely independent of them (fig. 1). Fertilization of thinned stands appears to stimulate volume growth in larger diameter classes to a greater extent than that in smaller diameter classes irrespective of stocking levels prior to thinning. Apparently in overstocked stands with severely suppressed individual tree crowns, N fertilization is required to rejuvenate individual tree crowns in order for the trees to respond to the additional crown space provided by thinning.

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INFLUENCE OF PRUNING ON WOOD GROWTH AND PRODUCT VOLUME IN A LOBLOLLY PINE PLANTATION[1]

Terry R. Clason and Charles T. Stiff[2]

Abstract.--Effects of one-and two-step pruning on tree growth were studied.At age 6, a precommercial thinning and a pruning to 1/2 total tree height were applied singularly or in combination. Five years later, plots treated initially were thinned to 100, 200, or 300 trees per acre and residual trees pruned to 17 feet. On plots thinned to 100 trees per acre, trees pruned at age 6 but not thinned were significantly smaller than either of the precommercially thinned one-or two-step prunings. Two-step pruning, applied with a precommercial thinning, did not reduce tree growth.

INTRODUCTION

On a given site, loblolly pine stands of similar age and composition will produce the same total stem cubic-foot volume over a range of stocking densities. However, how the wood yield is distributed among products on individual trees will influence the stand's ultimate value. Quite often, higher value can be attained by growing a small number of large diameter trees suitable for lumber and plywood. Various silvicultural practices can be used to manipulate stand composition and density to yield high-quality crop trees in the shortest possible time.

Practices such as site preparation, artificial regeneration, hardwood brush control, and early and frequent thinnings are extremely beneficial to the rapid growth of high-value pine plantations. Pruning, which enhances formation of knot-free wood, could contribute significantly to the development of premium sawtimber trees. When used in conjunction with other high-yield silvicultural practices, such as thinning, pruning schedules can be developed to maximize knot-free wood formation. This report discusses the effect of one-and two-step pruning schedules on sawtimber production and quality in a 29-year-old loblolly pine (*Pinus taeda L.*) plantation.

MATERIAL AND METHODS

Data

Data were collected from a 29-year-old loblolly pine plantation located on the North Louisiana Hill Farm Experiment Station near Homer, Louisiana. Research plots were established on an abandoned cotton field with soil types mainly from the Shubuta, Luverne and Bowie Series, all having a fine sandy loam texture. Site index averaged 68 feet on a 25-year base, with site quality of individual plots ranging from 65 to 78 feet.

In February 1950, bare rooted seedlings, graded as 1 and 2 by Wakeley's (1954) grading system, were planted on the 10-acre study area. Seedlings were grown from loblolly seed collected by the Louisiana Forestry Commission from natural stands located in North Louisiana. Prior to planting, site preparation included cutting existing pine and hardwood saplings, poisoning stumps and burning.

Within the study area two 1-acre blocks each were planted at 4x4, 6x6, 6x8, 8x8, and 10x10-foot spacings. Survival rates were generally high but interplanting was done where necessary. Hardwood competition and pine mortality on one 10x10-foot block necessitated its exclusion from the study.

In 1955 at age 6, each block was sub-divided into 4 plots. Measurement areas ranged from 0.16 to 0.29 acres without buffer strips. Three cultural treatments were randomly assigned to each block:

1. Precommercially thin (PCT) to 400 trees per acre (TPA);

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2. Prune (PRN) 400 crop TPA to 8 feet or 1/2 total height;

3. Precommercially thin to 400 TPA and prune to 8 feet or 1/2 total height (PCT x PRN).

The fourth plot in each block was maintained untreated as part of the original spacing study. From 1955 to 1960, diameter and height were measured annually on crop trees only. Subsequent data analyses were done assuming no treatment effect from initial spacing treatments.

Five years later at age 11, three commercial thinning treatments were applied to the previously treated plots. Treatments included:

1. Thin to 100 TPA (T100) and prune to 17 feet;

2. Thin to 200 TPA (T200) and prune to 17 feet;

3. Thin to 300 TPA (T300) and prune to 17 feet.

The 1960 treatments were replicated three times on each 1955 treatment and growth data were collected on a periodic basis from 1960 through 1978. Resulting age 6 and age 11 treatment combinations summarized in Table 1 provide a comparison between one-and two-step pruning schedules.

Table 1.--Treatment designations for age 6 and 11 treatment combinations[1]

Age 6 Treatments	Age 11 Treatments		
	T100	T200	T300
PCT	TRT11	TRT12	TRT13
PRN	TRT21	TRT22	TRT23
PCT x PRN	TRT31	TRT32	TRT33

[1] TRT11, TRT12, and TRT13 specify one-step pruning schedules, while other combinations indicate two-step prunings.

Times required to apply the 1955 and 1960 treatments were recorded. Precommercial thinning was accomplished with a hand bow saw at the rate of 60 trees per hour. Pruning, which was done with a pole pruning saw, averaged 12.5 trees per hour in 1955 and 6.6 trees per hour in 1960. The average times required per tree for each pruning schedule were 9.1 minutes for a one-step and 13.9 minutes for a two-step schedule. Pulpwood volumes removed during the 1960 thinning at age 11 were 10.3, 6.7, and 5.1 cords for 100, 200 and 300 TPA plots, respectively.

Taper data were collected on 454 felled trees in 1978 at age 29. Individual tree volumes, both inside and outside bark, were accumulated from a 6-inch stump to the tree top. In addition, analytically derived individual tree cubic-foot product volumes were computed under the following assumed merchantability standards:

1. Butt bolt - cubic feet in the first 8.3-foot sawlog;
2. Butt log - cubic feet in the first 16.7-foot sawlog;
3. Sawlogs - top dib $\geq$ 8 inches;
4. Chip-n -sawlog - 6 inches $\leq$ top dib $<$ 8 inches;
5. Chips - 3 inches $\leq$ top dib $<$ 6 inches;
6. Top - top dib $<$3 inches.

In this way, individual tree product mix was maximized. Volumes were calculated for 2-foot 1-inch sections via the following conic formula:

$$V_i = 0.0021513847 \{ D_i^2 + d_i^2 + D_i d_i L_i \} \qquad (1)$$

where,

V_i = cubic-foot volume of the ith conic section, $i = 1, 2, \ldots, m$;

D_i = diameter (inches) of the large end of the ith section;

d_i = diameter (inches) of the small end of the ith section;

L_i = length (feet) of the ith section.

Analysis

Analysis of covariance (ANOCOV) was utilized to test for treatment interaction differences in plot attributes by the following linear model:

$$W_{ijk} = \mu + (\alpha\beta)_{ij} + \gamma X_{ijk} + \varepsilon_{ijk} \qquad (2)$$

where,

W_{ijk} = value of the plot attribute for the ith treatment 1955, $i = 1, 2, 3$; and the jth treatment 1960, $j = 1, 2, 3$; and kth observation, $k = 1, 2, \ldots l_{ij}$;

μ = true mean of the population;

$(\alpha\beta)_{ij}$ = the interaction between ith treatment 1955 and jth treatment 1960;

γX_{ijk} = regression of W_{ijk} on X_{ijk}, where X_{ijk} = site index;

ε_{ijk} = error component.

Site index was used as a covariate to adjust for site quality differences in the comparisons.

Data were also analyzed to determine effect of pruning on total merchantable volume, total sawlog volume, and butt bolt and butt log volume. Treatment effects were tested by ANOCOV with the following linear model:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \gamma X_{ijk} + \varepsilon_{ijk} \qquad (3)$$

where,

Y_{ijk} = individual tree cubic-foot volume for the ith treatment 1955, i = 1, 2, 3; the jth treatment 1960, j = 1, 2, 3; and the kth observation, k = 1, 2, ..., n_{ij};

μ = true mean of the population;

α_i = the effect from the ith treatment 1955;

β_j = the effect from the jth treatment 1960;

$(\alpha\beta)_{ij}$ = the interaction between the ith treatment 1955 and the jth treatment 1960;

γX_{ijk} = regression of Y_{ijk} on X_{ijk}, where X_{ijk} = site index;

ε_{ijk} = error component.

Means for both plot attributes and felled trees were tested orthogonally at the $\alpha = 0.10$ level.

Percent clear wood determinations were made from 90 sawn butt logs for grade "D" and better lumber. Logs were 16.5 feet long and averaged 10.8 inches at the small end. Since individual log data were not available, differences in percent clearwood by treatment combination were not analyzed.

RESULTS

Diameter growth on the research plots was significantly influenced by both thinning and pruning treatments applied at age 6. Foil *et al.* (1964) reported that precommercial thinning significantly stimulated diameter growth, regardless of pruning. However, pruning to 1/2 tree height exerted a negative response, especially during the first three years. By age 11, thinned plot (PCT) diameter increment was 1.0 and 0.6 inch greater than the pruned (PRN), and the thinned and pruned plots (PCT x PRN), respectively. Detrimental effects on diameter growth from pruning 45 percent or more live crown have been substantiated by other studies (Labyak and Schumacher 1954, Young and Kramer 1972, and Banks and Prevost 1976). Also, Banks and Prevost (1976) indicated that following a severe pruning adjacent unpruned trees generally grow at a faster rate and surpass the pruned trees.

The age 11 thinning treatments (T100, T200 and T300) affected individual tree diameter growth significantly. Differences in diameter growth between thinning intensities were significant at ages 14, 23, and 28 (Foil *et al.* 1964, Shepard 1974, and Sprinz *et al.* 1979). The 17-year period following thinning resulted in a 7.5, 5.6, and 4.4-inch diameter growth increment in the 100, 200 and 300 TPA plots, respectively. During this same period, growth increments on age 6 treatments did not differ and averaged 6.5 inches.

Plot Analysis

Thinning treatments applied at age 11 affected plot diameter class distribution. By age 29, relative cumulative frequency of diameters larger than 10 inches increased as thinning intensity increased (Fig. 1). More than 95 percent of tree diameters on plots thinned to 100 TPA were larger than 10 inches. The 11-inch and larger diameter classes accounted for 72 and 50 percent of the trees on 200 and 300 TPA plots, respectively.

In the analysis of age 6 and 11 treatment effects, the influence of different pruning schedules on stand growth and development were not discernible. However, comparisons between average plot diameters at age 29 by age 6 treatments within age 11 treatments (Table 1) revealed that pruning schedules have affected stand development (Table 2). Significant differences existed between the age 6 treatments thinned to 100 TPA at age 11. Average diameter on the TRT21 plots was significantly smaller than TRT11 and TRT31. No difference was detected between TRT11 and TRT31. Thus, a two-step pruning

Table 2. Average plot attributes by treatment combination for 29-year-old loblolly pine.

Plot Attribute	Treatment								
	TRT11	TRT12	TRT13	TRT21	TRT22	TRT23	TRT31	TRT32	TRT33
n	3	3	2	3	3	3	3	3	3
Dbh[1] (in.)	15.3^{a} ±0.3	11.4^{c} ±0.3	10.9^{d} ±0.4	13.7^{b} ±0.3	11.9^{c} ±0.3	10.3^{d} ±0.3	15.0^{a} ±0.3	11.6^{c} ±0.3	10.3^{d} ±0.3
Height (ft.)	75.6 ±4.7	74.3 ±4.2	70.9 ±0.1	74.2 ±2.9	71.6 ±2.6	72.8 ±7.7	71.6 ±2.2	73.8 ±0.8	71.9 ±4.6
Site Index (ft.)	70.5 ±3.3	70.6 ±4.4	67.2 ±1.6	69.1 ±2.3	66.8 ±1.0	69.6 ±7.3	67.1 ±1.5	69.0 ±1.6	70.1 ±3.2
Basal Area[1] (ft^2/acre)	117^{a} ±8	120^{a} ±8	130^{a} ±10	95^{b} ±8	127^{a} ±8	122^{a} ±8	114^{a} ±8	114^{a} ±8	127^{a} ±8
Volume o.b.[1] (ft^3/acre)	4210^{a} ±318	4291^{a} ±319	4654^{a} ±388	3408^{b} ±313	4599^{a} ±323	4454^{a} ±314	4093^{a} ±320	4120^{a} ±313	4458^{a} ±316
Volume i.b.[1] (ft^3/acre)	3320^{a} ±250	3369^{a} ±251	3651^{a} ±305	2684^{b} ±246	3615^{a} ±254	3491^{a} ±247	3228^{a} ±252	3236^{a} ±246	3493^{a} ±248

[1] Least square means: means with the same letter for each response variable do not differ significantly at the $\alpha = 0.10$ level.

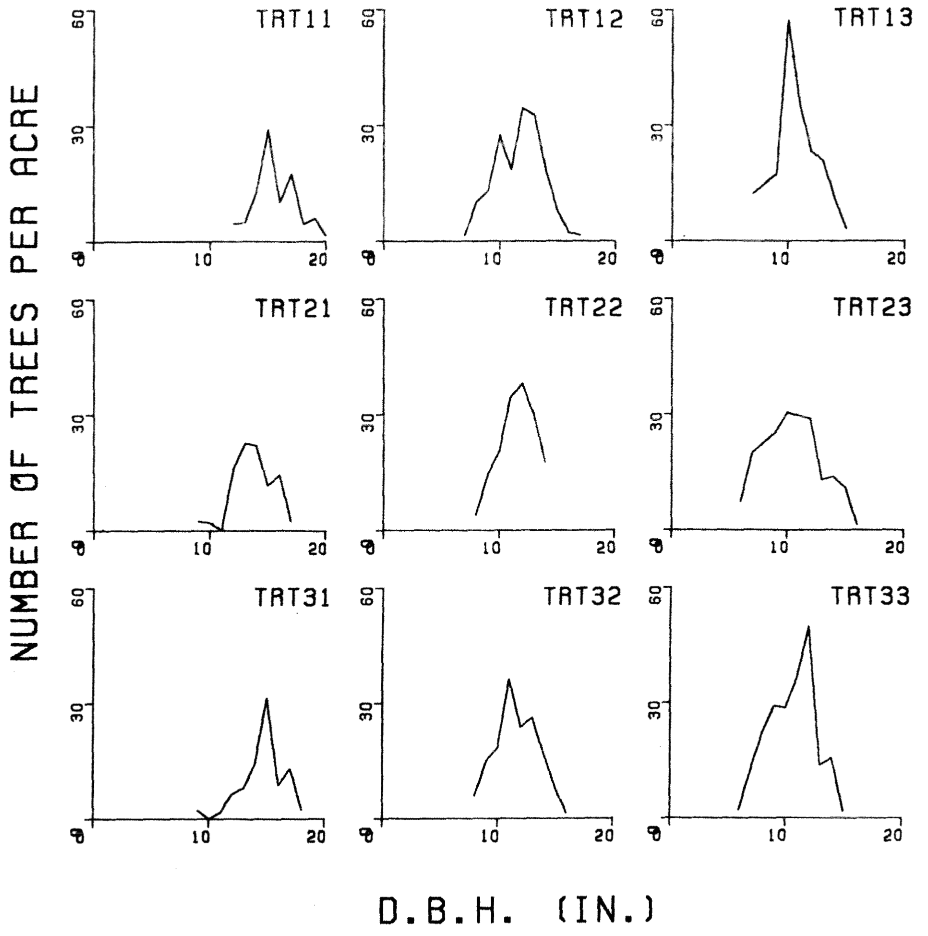

Figure 1. Diameter class distributions by treatment combinations prior to 1978 thinning for 29-year-old loblolly pine.

schedule, applied in conjunction with a precommercial thinning, followed by a subsequent stocking reduction to 100 TPA, did not reduce average stand diameter any more than a one-step pruning. However, pruning without precommercial thinning resulted in reduced diameter growth.

Similar comparisons for 200 and 300 TPA plots indicated nonsignificant differences (Table 2). Apparently, individual tree competition on the 200 and 300 TPA plots was such that the growth advantage manifested at age 11 on PCT plots was lost by age 29.

Basal area and volume decreased as stand density decreased (Table 2). Except for TRT21, differences between combinations were nonsignificant.

Bennett (1955) stated the advantage of two-step over one-step pruning was a greater production of clear wood. Percent clear wood in the butt sawlogs in Table 3 support that contention. However, as stated previously, individual log observations were unavailable for analyzing treatment differences. Both two-step pruning schedules yielded 50 to 100 percent more clear wood than the one-step.

Table 3. Percent clear wood by treatment combination for 29-year-old loblolly pine.

Treatment	Number logs	Average diameter (Inches)	Average log volume (ft^3)	Percent clear wood
TRT11	19	11.5	14.5	14.6
TRT12	8	10.8	12.4	17.5
TRT13	8	10.6	12.3	3.9
TRT21	14	11.1	13.4	28.8
TRT22	7	10.8	11.7	24.0
TRT23	10	11.0	12.9	24.0
TRT31	13	10.5	12.7	24.3
TRT32	8	10.8	12.0	22.3
TRT33	4	10.1	10.7	12.9

Table 4. Diameter class distributions of 454 felled trees by treatment combination for 29-year-old loblolly pine.

Treatment	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Total	Ave. Dbh (in.)
	number of trees															
TRT11							2	2	2	7	5	3	1	1	23	14.86 ±0.41
TRT12		1	4	8	11	8	10	10	3	3	1				59	10.87 ±0.25
TRT13		4	5	7	18	8	5	3	1	1					52	10.35 ±0.27
TRT21				1	1	0	4	5	7	5	4				27	13.46 ±0.37
TRT22			2	7	9	12	11	8	3	0	1				53	11.32 ±0.23
TRT23	3	11	12	11	15	13	9	3	6	4					87	9.86 ±0.21
TRT31				1	0	0	2	1	4	5	0	2	1		16	14.34 ±0.47
TRT32			3	10	12	17	8	9	4	2					65	11.10 ±0.24
TRT33	1	6	10	12	11	11	13	4	4						72	9.86 ±0.23
TOTAL	4	22	36	57	77	69	64	45	34	27	11	5	2	1	454	

Individual Tree Stem Analysis

Diameter class distributions of the 454 felled trees by treatment combination (Table 4) are similar to the 1978 treatment diameter distributions of all trees (Fig. 1). Average d.b.h. for the felled trees was slightly less but still within two standard deviations of the average plot diameter (Tables 2 and 4). Thus, individual tree volumes from the felled trees provided a representative sample for the analyses.

Table 5 shows age 6 and 11 treatment effects on individual tree volumes. At age 29, significant differences were expressed only among the age 11 treatments. Total individual tree volume and all sawlog volumes increased as thinning intensity increased. The percentage of total stem volume present in the butt sawlog was 43, 33, and 22 percent for the 100, 200 and 300 TPA plots, respectively.

TRT11, TRT21, and TRT31 were the only treatment combinations significantly affected by the different pruning schedules (Table 6). Trees receiving a two-step pruning without a precommercial thinning had significantly less total, sawlog, butt log and butt bolt volumes than the precommercially thinned treatments. No volume differences were detected between TRT11 and TRT31. Butt log volume accounted for 42, 42, and 45 percent of the total volume for TRT11, TRT21, and TRT31, respectively.

Individual tree cubic-foot product breakdowns by treatment combinations appear in Table 7. Cubic-foot product volumes for total, sawlog, butt log and butt bolt are essentially the same as the adjusted volumes found in Tables 5 and 6. Volume of lower value products, chips and chip-n-sawlogs, increased as thinning intensity decreased.

DISCUSSION

Guidelines for pruning have been discussed in previous studies involving the development of premium sawtimber trees. Labyak and Schumacher (1954) suggested pruning a selected number of crop trees in fully-stocked stands accompanied by a severe thinning to preclude further natural pruning. Bennett (1955) recommended a practical schedule for pruning wider-spaced, old-field, slash pine plantations on good sites. His schedule is similar to that utilized in the present study. In addition, timing of pruning should be based on height, diameter and taper characteristics of the 100 largest trees per acre (Banks and Prevost 1976). The first pruning should be done when average tree diameter is 4.0 inches (Vel 1975). Locatelli (1977) stated pruning would be profitable, provided only crop trees are pruned and pruning is done on at least 7-acre blocks.

The present study has shown that guidelines stated above can be used to produce premium sawlog

Table 5. Least square means cubic-foot product volumes (i.b.) for 454 felled trees by age 6 and 11 treatments for 29-year-old loblolly pine.[1/]

	Age 6 Treatment			Age 11 Treatment		
Volume type	TRT1_	TRT2_	TRT3_	TRT_1	TRT_2	TRT_3
	ft^3					
Total	21.75 ±0.70	20.51 ±0.61	20.88 ±0.72	29.91^a ±0.92	18.33^b ±0.53	14.90^c ±0.52
Sawlog	14.79 ±0.82	13.78 ±0.72	13.90 ±0.86	25.15^a ±1.07	10.68^b ±0.62	6.65^c ±0.61
Butt log	7.39 ±0.44	7.16 ±0.38	7.53 ±0.46	12.88^a ±0.58	5.93^b ±0.33	3.27^c ±0.33
Butt bolt	4.44 ±0.23	4.20 ±0.20	4.35 ±0.24	7.16^a ±0.31	3.57^b ±0.18	2.25^c ±0.17

[1/] Means with the same letter for each response variable do not differ significantly at the α = 0.10 level.

Table 6. Least square means cubic-foot product volumes (i.b.) for 454 felled trees by treatment combinations for 29-year-old loblolly pine.[1/]

Volume type	Treatment TRT11	TRT12	TRT13	TRT21	TRT22	TRT23	TRT31	TRT32	TRT33
	ft³								
Total	32.70^a ±1.56	17.45^c ±0.98	15.09^d ±1.04	27.46^b ±1.42	18.96^c ±0.88	15.11^d ±0.80	29.56^a ±1.81	18.59^c ±0.93	14.50^d ±0.88
Sawlog	28.16^a ±1.82	9.65^c ±1.14	6.56^d ±1.22	22.26^b ±1.67	11.82^c ±1.03	7.27^d ±0.93	25.03^a ±2.11	10.57^c ±1.08	6.11^d ±1.02
Butt log	13.79^a ±0.98	5.27^c ±0.61	3.12^d ±0.65	11.43^b ±0.89	6.69^c ±0.55	3.36^d ±0.50	13.43^a ±1.13	5.82^c ±0.57	3.34^d ±0.55
Butt bolt	7.64^a ±0.52	3.26^c ±0.33	2.43^d ±0.35	6.39^b ±0.48	3.98^c ±0.29	2.23^d ±0.27	7.47^a ±0.60	3.47^c ±0.31	2.11^d ±0.29

[1/] Means with the same letter for each response variable do not differ significantly at the $\alpha = 0.10$ level.

Table 7. Average individual tree cubic-foot volume (i.b.) product breakdown by treatment combination for 29-year-old loblolly pine.

Volume type	Treatment TRT11	TRT12	TRT13	TRT21	TRT22	TRT23	TRT31	TRT32	TRT33
	ft³								
Butt bolt	8.1 ±1.8	3.6 ±2.7	2.1 ±2.4	6.5 ±2.3	3.8 ±2.3	2.4 ±2.7	7.3 ±2.7	3.4 ±2.6	2.3 ±2.5
Butt log	14.6 ±3.3	5.9 ±5.1	2.5 ±4.0	11.7 ±4.1	6.3 ±4.7	3.7 ±5.1	13.0 ±4.8	5.8 ±4.9	3.4 ±4.7
Sawlog	29.9 ±8.8	10.9 ±9.5	5.2 ±6.4	22.7 ±9.0	10.9 ±8.2	8.0 ±10.1	24.3 ±11.2	10.4 ±8.9	6.9 ±8.1
Chip-n-Saw	2.4 ±1.3	4.3 ±1.9	4.6 ±2.3	2.6 ±1.4	4.4 ±1.8	4.1 ±2.8	2.3 ±1.8	4.7 ±2.0	4.4 ±2.5
Chips	1.9 ±0.7	3.2 ±1.5	3.9 ±1.3	2.4 ±0.6	2.8 ±1.3	3.5 ±1.6	2.0 ±0.7	3.1 ±1.1	3.7 ±1.5
Top	0.1 ±0.1	0.2 ±0.1	0.1 ±0.1	0.2 ±0.1	0.2 ±0.1	0.2 ±0.1	0.1 ±0.1	0.1 ±0.1	0.2 ±0.1
Total	34.3 ±8.0	18.6 ±8.0	13.9 ±5.6	27.9 ±7.9	18.2 ±6.4	15.7 ±9.0	28.8 ±9.8	18.5 ±7.1	15.2 ±7.2

trees containing up to 28 percent clear wood in the butt logs on a 30-year rotation. As the demand for clear wood increases, pruned sawtimber trees will increase in importance and value.

CONCLUSIONS

1. Two-step pruning is required for maximum clear wood formation in butt sawlogs.
2. First-phase pruning of 100 to 125 crop TPA should include a precommercial thinning to 400 TPA.
3. Second-phase pruning should be done in conjunction with a severe commercial thinning to 100 TPA.

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SOME SHORT-TERM EFFECTS OF THINNING AND PRUNING IN YOUNG LOBLOLLY PINE PLANTATIONS[1]

James D. Burton[2]

Abstract.--Three years after an old-field loblolly pine plantation was thinned and pruned to 4 basal areas and 3 live crown ratios, stemwood volume growth was greatest under the lightest thinning and unaffected by pruning. Stem form improved most under the severest thinning and pruning.

INTRODUCTION

Loblolly pine sawtimber can be grown in plantations in rotations of 21 to 27 years, with heavy thinning, low pruning, and understory control (Burton and Shoulders 1974). But how would lighter levels of thinning and higher levels of pruning affect stemwood volume growth early in the rotation? This paper reports some 3rd-year results of a study established to answer this question.

PROCEDURES

Description of Study Area

The study was installed in an old-field loblolly pine plantation near Monticello, Ark.[3] The stand had been machine-planted at a spacing of about 6 by 6 ft. in winter 1958-59. When the study began, the plantation was 11 years old. It contained 565 pine stems/acre with a basal area of 107 ft^2/acre. The d.b.h. range was 1 to 11 inches; 475 stems/acre were $\geq$ 4.6 inches d.b.h.; the 5-inch class had 18 percent of the total pine stems/acre, the 6-inch class had 32 percent, and the 7-inch class had 25 percent. Dominant and codominant trees averaged 37 feet tall, and their live crown length was 59 percent of total height.

The unthinned plantation had very few hardwood trees; none had a dominant or codominant crown, and all were felled when the study began. There was no woody understory at age 11.

The soils are Tippah and Sacul silt loams. The A1 horizon is 3 to 4 inches thick. Slopes are 0 to 4 percent to the south.

Thirty-six square 0.4-acre plots were laid out and were organized into three blocks according to severity of erosion that had occurred when the land was in row crops. In block I, where evidence of erosion was strongest, basal area averaged 99 ft^2/acre and no plot had less than 90 ft^2/acre. In block II no plot had less than 98 ft^2/acre, and in block III no plot had less than 105 ft^2/acre.

Treatments

At age 11, four thinning levels (very light, light, heavy, and very heavy) and three pruning levels (low, medium, and high) were applied in all 12 possible combinations. Thinning left basal areas of 100, 80, 60, or 40 ft^2/acre in merchantable trees ($\geq$ 4.6 inches d.b.h. containing $\geq$ two 63-inch bolts to a 3-inch top d.i.b.). Trees smaller than this were submerchantable and were removed in the first thinning. Where possible, thinning was from below. But need to achieve uniform spacing and to remove forked and crooked trees, wolf trees, and trees with fusiform rust stem galls required cutting many dominant and codominant trees; so did the reduction of basal area to 40 ft^2/acre.

The low level of pruning left a live crown 19 feet long, equal to 52 percent of tree height. High pruning left a crown length of 13 feet (37 percent), and medium pruning left a 15-ft. crown (41 percent).

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[3] Land and technical assistance were provided by the Crossett Division, Georgia-Pacific Corporation.

The low level of pruning was mild; in lightly and very lightly thinned plots, most trees had some lower limbs dead of suppression at age 14. Even under very heavy thinning, low pruning did not greatly reduce the photosynthetic capacity. High pruning did: some trees had only 2 annual whorls, with intervening short branches, and the leader.

Measurements and Analysis

All measurements were made in the 0.1-acre square plot at the center of each 0.4-acre treatment plot. The plots were inventoried before treatment at age 11 and before treatment at age 14. The first and every fifth tree measured in each 1-inch d.b.h. class (≥ 4.6 inches) were chosen as sample trees for additional measurements until each plot had 12 sample trees. I measured upper bole diameters and heights with a magnifying optical dendrometer and got bole volumes, total and to a 4-inch top, by the height accumulation method (Lohrey and Dell 1969). To obtain stemwood diameter inside bark from stem diameter outside bark, I derived a conversion factor from paired d.o.b. and d.i.b. measurements at 4 points along the stem of 108 trees felled in thinning.

The height accumulation program computed cubic-foot volume and basal area for each sample tree. The summary program computed volume/acre of each plot by multiplying the mean volume/basal area ratio of the sample trees by the plot basal area/acre. After-cut volume/acre was determined from the mean volume/basal area ratio of sample trees left (usually fewer than 12 trees) and the after-cut basal area/acre.

Absolute form quotient was calculated as:

$$\text{AFQ} = \frac{\text{(bole d.o.b. midway between b.h. and apex)}}{\text{d.b.h.}}$$

Using randomized complete blocks with 3 replications, I examined treatment-associated differences in growth parameters through analysis of variance. I used Duncan's Multiple Range Test to evaluate differences between treatment means when the thinning and pruning interaction was significant (at the .05 level) and to evaluate main effects of thinning and pruning when interaction was not significant.

RESULTS

Growth in D.b.h.

Periodic growth in d.b.h. was greatest in the very heavy, least in the very light thinning treatment, and all four thinning means were significantly different (table 1). Annual d.b.h. growth between ages 11 and 14 averaged .59 inch in the very heavy, .45 inch in the heavy, .34 inch in the light, and .27 inch in the very light. Growth in d.b.h. was significantly less under high than under low pruning. The thinning and pruning interaction was not significant.

Table 1.--Periodic growth in mean d.b.h., age 11-14, of trees surviving to age 14

Pruning level	Thinning level Very heavy	Heavy	Light	Very light	Pruning means
	-----------inches	----------	----------	----------	
High	1.61	1.30	.92	.80	1.16 a[1/]
Medium	1.79	1.37	1.00	.78	1.24 ab
Low	1.87	1.38	1.12	.80	1.29 b
Thinning means	1.76 a	1.35 b	1.02 c	.80 d	1.23

1/ Means followed by the same letter, within a row or a column, are not significantly different at the .05 level.

For all surviving trees, periodic growth in d.b.h. per foot of height growth was significantly less under high pruning than under low pruning and was nearly twice as great under very heavy thinning as under light and very light thinning (table 2). With greatly increased growing space, trees became more stocky; with high pruning, trees became more slender. Treatments affected stem form.

Table 2.--Periodic d.b.h. growth per foot of periodic height growth

Pruning level	Thinning level Very heavy	Heavy	Light	Very light	Pruning means
	-----------inches	----------	----------	----------	
High	.25	.19	.14	.12	.18 a[1/]
Medium	.26	.19	.17	.14	.19 ab
Low	.32	.19	.16	.15	.21 b
Thinning means	.28 a	.19 b	.16 c	.14 c	.19

1/ Means followed by the same letter, within a row or a column, are not significantly different at the .05 level.

Table 3.--Periodic annual growth in total stemwood, inside bark, including leader

Pruning level	Thinning level Very heavy	Heavy	Light	Very light	Pruning means
	----------ft^3/acre----------				
High	228	286	280	320	279 a[1]
Medium	220	284	310	308	280 a
Low	232	287	334	356	302 a
Thinning means	227 a	286 b	308 bc	328 c	287

[1] Means followed by the same letter, within a row or a column, are not significantly different at the .05 level.

Growth in Cubic-Foot Volume and Height to a 6-inch Top

Growth in total stemwood, inside bark to a zero top, was significantly lower with heavy thinning, and even lower with very heavy thinning, than with very light thinning (table 3). With all pruning levels combined, periodic annual growth ranged from 328 ft^3/acre under very light thinning to 227 ft^3/acre under very heavy. There were no important differences among pruning means.

Periodic annual growth in height to a 6-inch top was greatest under very heavy thinning, significantly less under heavy, and even less under light and very light thinning (table 4). There were no important differences among pruning means.

Basal Area Growth

Periodic annual growth in basal area was greatest under low pruning and significantly reduced by medium and high pruning (table 5); but it was vigorous in every treatment. Differences among thinning means were not important.

Stem Form

Absolute form quotient increased under all treatments: stem form became more cylindrical. Overall mean AFQ was .62 at age 11 and .65 at age 14. The interaction of thinning and pruning was significant: differences due to pruning occurred only under heavy and very heavy thinning (table 6). Under very heavy thinning, the high-pruning mean was greater than the low-pruning mean but not the medium pruning mean. Under light and very light thinning, pruning did not significantly affect stem form.

Table 4.--Periodic annual growth in height to a 6-inch top d.o.b. in sample trees

Pruning level	Thinning level Very heavy	Heavy	Light	Very light	Pruning means
	------------feet------------				
High	4.8	4.1	2.6	2.6	3.5 a[1]
Medium	4.3	3.3	2.5	2.4	3.1 a
Low	4.0	3.3	3.1	2.3	3.2 a
Thinning means	4.3 a	3.6 b	2.7 c	2.4 c	3.3

[1] Means followed by the same letter, within a row or a column, are not significantly different at the .05 level.

Table 5.--Periodic annual growth in basal area

Pruning level	Thinning level Very heavy	Heavy	Light	Very light	Pruning means
	----------ft^2/acre----------				
High	7.11	7.89	8.00	8.22	7.81 a[1]
Medium	7.67	9.11	7.44	7.67	7.97 a
Low	8.67	9.11	9.33	9.00	9.03 b
Thinning means	7.81 a	8.70 b	8.26 ab	8.30 ab	8.27

Means followed by the same letter, within a row or a column, are not significantly different at the .05 level.

Table 6.--Periodic annual increase in absolute form quotient

Pruning level	Thinning level Very heavy	Heavy	Light	Very light	Pruning means
High	.049 a[1]	.039 ab	.021 c	.033 bc	.036
Medium	.029 bc	.036 b	.028 bc	.032 bc	.031
Low	.027 bc	.021 c	.021 c	.030 bc	.025
Thinning means	.035	.032	.023	.032	.030

[1] Means followed by the same letter, within a row or a column, are not significantly different at the .05 level.

DISCUSSION

Periodic basal area growth in young loblolly pine stands usually varies directly, but not greatly, with residual basal area, being only slightly affected by thinnings removing as much as 50 percent of pretreatment basal area (Wahlenberg 1960).

Under light and very light thinning, natural crown-shortening proceeded so far that artificial pruning actually did little to further shorten live-crown length. Heavy and very heavy thinning so thoroughly released the residual trees that natural pruning stopped temporarily. The lowest limbs remained alive and vigorous, and pruning them caused a real difference in stem form.

A thinning that removes dominant and codominant trees encourages development of increased taper in residual trees (table 2). Thinning from below ordinarily has no measurable effect on stem form (Larson 1963). Very light and light thinnings in this study were mainly from below, but heavy and very heavy thinning harvested many dominant-stand trees. The effect of pruning on stem form is directly opposite that of thinning from above. Research elsewhere (Luckhoff 1949, Labyak and Schumacher 1954, and Marts 1949, among others) with loblolly pine and other conifers, has shown that removal of $\geq$ 20 percent of the green crown reduces diameter growth and causes trees to develop a more cylindrical bole. After a few years, stem taper and growth rate return to normal, if prunings are not repeated. This return to normal does not mean that d.b.h. of pruned trees will soon equal that of the unpruned. Stem form in young even-aged pine stands during the linear period of height growth improves rapidly with increasing age (Larson 1963). Williston (1967) reported that form class of crop trees in loblolly pine plantations in Tennessee, from age 19 to age 29, increased more in plots thinned from below than in unthinned plots. In thinning studies elsewhere (Boggess and McMillan 1955, Brinkman et al. 1965) in pine plantations and natural stands, the largest, fastest-growing trees developed the least taper and made the greatest short-term improvement in stem form. These differences usually are temporary; all surviving trees, without more cultural treatment, usually approach a common stem form characteristic of the species and tree size.

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DIAMETER DISTRIBUTIONS MODELS
FOR
REPEATEDLY THINNED SLASH PINE PLANTATIONS[1]

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Abstract.--This paper reports the results of an effort to determine if traditional diameter distribution modeling methods can be applied to repeatedly thinned pine plantations. Data are from 297 plots in slash pine plantations thinned and remeasured up to five times over a period of about 20 years. The Weibull distribution fitted diameter distributions quite well -- as well as it and other distributions have fitted data from unthinned stands. Models to predict and project the 24th, 63rd, and 93rd percentiles of distributions were developed for unthinned stands, stands after first thinning, and following a growth period of variable length. An analysis of before and after thinning distributions showed no difference except at the first thinning. The first thinning, primarily a thinning from below, tended to shift the distribution toward large trees (more negative skewness). An example is provided with the models applied to project the distributions before and after thinning at ages 15, 20, and 25 and final distribution at age 30.

INTRODUCTION

Foresters have long been interested in thinning as a method of stimulating growth and producing higher quality sawlogs. However, plantation forestry in the South and the Southeast has been characterized in the sixties and seventies by a "plant 'em thick and cut 'em quick" type of silviculture with almost total emphasis on pulp fiber production. There are no clear advantages to thinning in such a system. With increasing emphasis in recent years on solid wood products, primarily lumber and veneer, and a diminishing supply of high quality sawlogs from natural stands, interest has returned to the practice of thinning. Along with this returned emphasis comes a need to predict stand structure (volumes, tree heights, log lengths, etc., by diameter classes).

In this paper we report on an analysis which looked at one very important aspect of predicting stand structure of thinned plantations, the diameter distribution. Data from repeatedly thinned and remeasured slash pine plantations were analyzed to determine whether or not smooth distribution functions can be used as models, and if before and after thinning distributions are

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different in shape. Regression equations are presented which can be used to predict three diameter distribution percentiles for unthinned and thinned plantations of slash pine. A method of obtaining parameters of the Weibull distribution from the percentiles is also explained.

THE DATA BASE

Data for these analyses come from the Southeastern Forest Experiment Station study known as the Slash Pine Plantation Stand Density Study. Several publications have resulted, either totally or in part, from this study (Bennett, 1970; Bennett and Clutter, 1968; Field et al. 1978; and Clutter and Jones, 1980). Clutter and Jones (1980) give a brief overview of the study, part of which is repeated here for completeness. However, some details of the description of the data differ from their report since the analysis reported here is the first to use all remeasurements of the plots.

The study, begun in 1958, represents a cooperative effort of the USDA Forest Service, Southeastern Forest Experiment Station, and 18 landowners[1/]. The 297 plots (each approximately 1/4-acre in size) were distributed across 4 states,

State	Number of Plots
Georgia	180
Florida	104
Alabama	8
Mississippi	5
	297

and across 3 physiographic provinces,

Province	Number of Plots
Upper Coastal Plain	65
Middle Coastal Plain	145
Lower Coastal Plain	87
	297

Plantations sampled had been established on old-fields and had no evidence of frequent or damaging fires, naval stores operations, heavy rust infection, or interplanting. No more than six merchantable-size wild pines or hardwoods were allowed on a selected plot.

Each plot was randomly assigned a residual basal area class for thinning treatment,

Basal Area Class -square feet-	Number of Plots
15	3
40	69
65	71
90	69
115	49
140	27
165	9

At each measurement, including installation, each plot was thinned to the midpoint ($\pm$ 12.5 square feet) of its assigned class if not already within the class range. This was done with an improvement cut from below, removing mostly smaller trees with some large trees taken if disease, poor stem quality, or spacing justified their removal. The leaving of large, unoccupied spaces in stands was avoided. Plots were well distributed over ages 9 to 32 years, site index (base age 25) 38 to 80 feet, and 100 to 1180 trees per acre at age of installation (Tables 1-3).

Table 1.--Slash Pine Stand Density Study--Distribution of plots by age at installation and site index (base age 25).

Age Class	Site Index Class (feet)					
	30-39	40-49	50-59	60-69	70-79	80-89
	---------number of plots---------					
10	1	4	9	48	37	0
15	0	5	18	49	8	0
20	2	0	13	42	27	1
25	0	1	6	16	4	0
30	0	0	2	4	0	0
Total	3	10	48	159	76	1

At plot installation (measurement number 1) and at each subsequent remeasurement, all diameters were recorded to the nearest tenth of an inch. Total height, height to live crown, and crown class were recorded on the first and every eighth tree thereafter in each diameter class encountered. Thinnings were carried out at 646 of the 1188 total plot visits (Table 4). Nine plots were never remeasured after installation while 13 plots were remeasured 5 times. The interval between measurements ranged from one to ten years with the majority of plots being remeasured on a 5-year cycle:

[1/] In alphabetical order: Brunswick Pulp Land Company; Buckeye Cellulose Corporation; Container Corporation of America; Continental Forest Industries; Florida Department of Agriculture and Consumer Services, Division of Forestry; Georgia Kraft Company; International Paper Company; ITT Rayonier, Incorporated; O. F. McEachin Estate, McRae, Georgia; Jesse Newsom Estate, Davisboro, Georgia; Owens-Illinois, Forest Products Division; Mr. W. C. Peterson, Soperton, Georgia; Mr. Joe Prescott, Lumber City, Georgia; St. Regis Paper Company; Sullivan Lumber Company; Union Camp Corporation; U.S. Forest Service, Florida National Forests; and H. E. Walton Estate, Cordele, Georgia.

Table 2.--Slash Pine Stand Density Study--Distribution of plots by age and stems per acre at installation.

Age Class	Stems Per Acre											Total
	100-199	200-299	300-399	400-499	500-599	600-699	700-799	800-899	900-999	1000-1099	1100-1199	
	number of plots											
10	0	1	2	18	27	20	16	6	4	2	3	99
15	4	13	15	14	10	13	7	2	2	0	0	80
20	16	19	22	16	4	5	0	0	2	0	1	85
25	12	9	1	3	2	0	0	0	0	0	0	27
30	4	2	0	0	0	0	0	0	0	0	0	6
Total	36	44	40	51	43	38	23	8	8	2	4	297

Table 3.--Slash Pine Stand Density Study--Distribution of plots by site index (base age 25) and stems per acre at installation.

Site Index	Stems Per Acre											Total
	100-199	200-299	300-399	400-499	500-599	600-699	700-799	800-899	900-999	1000-1099	1100-1199	
	number of plots											
30-39	1	0	1	0	0	0	1	0	0	0	0	3
40-49	0	2	3	1	0	0	2	1	0	1	0	10
50-59	5	6	6	11	7	7	0	2	4	0	0	48
60-69	23	26	17	29	19	18	13	5	4	1	4	159
70-79	7	9	13	10	17	13	7	0	0	0	0	76
80-89	0	1	0	0	0	0	0	0	0	0	0	1
Total	36	44	40	51	43	38	23	8	8	2	4	297

Growth Period Length	Number of Cases
--years--	
1	12
2	14
3	25
4	62
5	716
6	50
7	8
8	3
9	0
10	1

ANALYSIS AND MODEL DEVELOPMENT

Testing Smooth Distribution Curves

Since the turn of the century smooth distribution curves of several types, primarily statistical distribution functions, have been used in forestry to characterize distributions of diameters. Most recent diameter distribution modeling work for unthinned conifer plantations has relied on the Weibull distribution introduced for this purpose by Bailey and Dell (1973). This function has also found use in modeling natural stands of conifers (Schreuder et al., 1979), natural mixed-species of Appalachian hardwoods (Stiff, 1979), and uneven-aged mixed northern hardwoods (Hyink, 1979). To our knowledge, the use of this function or any other smooth distribution function with data from thinned conifer stands has not been thoroughly explored.

The equation of the Weibull probability density function is

$$f(x) = (c/b)[(x-a)/b]^{c-1} e^{-[(x-a)/b]^c}, \quad a \leq x < \infty \qquad (1)$$

$$= 0, \quad \text{elsewhere,}$$

where x is d.b.h. and the coefficients, a, b, and c, must be estimated from data or predicted with models. Bailey and Dell (1973) discuss characteristics of the Weibull which make it useful as a diameter distribution model.

With the algorithm for maximum likelihood estimation proposed by Wingo (1972), equation (1) was fitted to data from each measurement of each plot both before and after thinning. Several checks for goodness of fit were then applied. The Kolmogorov-Smirnov test (Massey, 1951) at the 0.05 level rejected the Weibull for 5.02% of the before-thinning cases and 4.67% of the after-thinning cases. Before and after thinning refers to the stand immediately before and after trees are removed, without regard to the overall thinning history of the stand. As another check, quadratic mean diameter (D_q), minimum diameter (D_m), and maximum diameter (D_x) were compared for the observed and fitted distributions. Defining deviations by the function

$$\Delta(y) = (\text{observed } y) - (\text{predicted } y),$$

summaries were developed for $\Delta(D_q)$, $\Delta(D_m)$, and $\Delta(D_x)$. The after-thinning data fitted the Weibull model as well as the before-thinning data (Table 5). In both instances, the fit was judged to be acceptable.

Table 4.--Slash Pine Stand Density Study--Numbers of plots by age at measurement and measurement number.

Age	Measurement Number						
	1	2	3	4	5	6	Totals
	----------number of plots---------						
9	6						6
10	17						17
11	26						26
12	29						29
13	27	3					30
14	24	3					27
15	8	15	1				24
16	11	29	0				40
17	24	33	0				57
18	12	25	4				41
19	14	12	4				30
20	16	4	9	1			30
21	24	9	23	0			56
22	16	20	37	3			76
23	11	20	18	4			53
24	13	11	18	2			44
25	2	16	6	11	1		36
26	7	17	8	40	0		72
27	4	32	26	12	0		74
28	0	5	9	26	3		43
29	1	16	10	5	2		34
30	2	1	8	6	0		17
31	0	4	26	13	8		51
32	3	7	21	15	4		50
33		0	14	7	12		33
34		1	9	2	2	2	16
35		2	1	17	0	0	20
36		0	3	25	8	0	36
37		3	7	18	5	0	33
38			1	11	7	3	22
39			0	4	2	5	11
40			2	0	3	1	6
41			0	7	3	0	10
42			0	3	12	2	17
43			3	0	4		7
44				0	5		5
45				2	0		2
46				0	0		0
47				3	2		5
48					0		0
49					0		0
50					0		0
51					2		2
Totals	297	288	268	237	85	13	1188

Table 5.--Summaries of deviations for quadratic mean (D_q), minimum (D_m), and maximum diameter (D_x).

Deviations[1/]	Before Thinning	After Thinning
---inches---	--------percent of cases--------	
$\Delta(D_q)$:		
-0.1 to +0.1	80	79
-0.3 to +0.3	96	96
-0.5 to +0.5	98	98
$\Delta(D_q) \leq 0$	40	44
$\Delta(D_q) \geq 0$	60	56
$\Delta(D_m)$:		
-1.0 to +1.0	74	76
-3.0 to +3.0	94	97
$\Delta(D_m) \leq 0$	60	57
$\Delta(D_m) \geq 0$	40	43
$\Delta(D_x)$:		
-1.0 to +1.0	92	95
-3.0 to +3.0	98	99
$\Delta(D_x) \leq 0$	75	71
$\Delta(D_x) \geq 0$	25	29

[1/] $\Delta(y)$ = (observed y) - (predicted y)

The next step was to examine whether or not thinning by the method applied in this study significantly changed the shape of the diameter distribution. In a row thinning, trees are not removed according to a size criterion, so an assumption that the before and after-thinning relative distributions are the same would be tenable. However, with the thinning methods applied in this study, size (diameter) and probability of removal should be inversely related. This could lead to a change in the relative distribution.

Again the Kolmogorov-Smirnov test was employed. When the observed distributions were converted to percentages and tests made at the 0.05 level for different underlying distributions before and after thinning, 11.4% (74 plot measurements) of the tests were significant. Of those, 68 cases were from initial thinnings. For stands which had been subjected to thinning in the past, only 1.6% of the cases had different before and after thinning distributions. This implies that once a thinning regime was started, thinnings subsequent to the first one did not alter the relative distribution of diameters. With these results in mind, we proceeded to design a system of regression equations to predict before and after thinning distributions and to predict change in the distribution due to growth based on the Weibull as a model.

Predicting the Weibull Parameters

Past applications of the diameter distribution approach to yield model development usually involved regressions to predict the parameters of a chosen distribution. Such regressions have been developed using either maximum likelihood or moment estimates for the parameters as dependent variables and stand characteristics (age, site index, trees per acre, etc.) as independent variables. In most published work, one or more of the parameters was poorly regressed ($r^2 \leq 0.10$). This has been true with both the beta distribution and the Weibull. It was true for our data as well. We could not obtain acceptable regressions to predict the maximum likelihood estimates of Weibull parameters.

A likely reason for the poorly defined regressions experienced is that quite similar appearing distributions, in terms of shape and peakedness, may result from different sets of parameter estimates. This is simply variation introduced through the fitting process. However, we reasoned that statistics computed directly from the data may be more predictable since no process of curve fitting would be involved. If reliable regressions could be obtained to predict those statistics, they could then be equated to theoretical values as defined with equation (1). The resulting system of equations could thus be solved for predicted values of the distribution parameters.

A number of different sample statistics could be used in this approach: mean, mode, variance, minimum and so on. For a 3-parameter model like equation (1), three such statistics would be necessary. Since the k'th moment of the Weibull probability density function contains the expression

$$\Gamma(1 + k/c) = \int_0^\infty t^{k/c} e^{-t} dt$$

and solving for c would lead to complications, we choose not to use moments. Instead, we elected to predict percentiles since the p'th distribution percentile of the Weibull is a tractable equation:

$$D_p = a + b[-\ln(\frac{100-p}{100})]^{(1/c)}, \qquad (2)$$

where D_p is that diameter such that exactly p percent of the trees in the stand are smaller.

For p we chose 24, 63, and 93. Although somewhat arbitrary and much work could be done toward defining optimum choices, our decision was based on the fact that Dubey (1967) showed p = 24 and p = 93 to be jointly best for estimation of b and c when a = 0 is specified (i.e. two-parameter Weibull). Further, p = 63 was chosen because this value gives D_p = a + b, a much simplified expression.

These three percentiles were computed directly from the measured diameters for each stand, both before and after thinning, at each measurement age. Linear interpolation was used where necessary to obtain the percentile. For example, if the 20th percentile was at 5.2 inches and the 25th percentile was at 5.3 inches,

$$D_{24} = 5.2 + 0.1(4/5)$$
$$= 5.28$$

With regression screening methods (SAS Institute, 1979), the following equations to predict these three percentiles for unthinned stands were obtained with data from measurements of stands not thinned up to the time of measurements:

$$D_{24u} = -8.0067 + 0.0662A -2.0764 \ln(T_s) + 6.0138 \ln(S) \quad (3)$$

$$R^2 = 0.72 \qquad s_{y.x} = 0.90$$

$$D_{63u} = 3.5796 + 2.8233 \ln(A) - 376.7283/S + 627.1906/T_s \quad (4)$$

$$R^2 = 0.93 \qquad s_{y.x} = 0.26$$

$$D_{93u} = -8.0355 + 4.1228 \ln(H) + 616.9904/T_s -65.6214/S\ , \quad (5)$$

$$R^2 = 0.92 \qquad s_{y.x} = 0.35,$$

where $\ln(H)$ = natural logarithm of dominant height (H) in feet,
A = age in years,
T_s = surviving trees per acre,
S = base-age-25 site index in feet,
and D_{pu} = the p'th percentile of the diameter distribution of an unthinned plantation.

Equations (3), (4), and (5) were used to predict distribution percentiles and equation (2) was used to define a system of 3 equations in the 3 parameters. Solution of the equations for a, b, and c allowed predicted distributions to be generated. Exact procedures for obtaining the solutions are covered in the next section of this paper. Based on the Kolmogorov-Smirnov test, only 3.1 percent of the predicted distributions were found different from the observed distributions at the 0.05 level. In addition, 78% of the cases had predicted quadratic mean diameters within ±0.5 inch of the observed (Table 6).

In some cases, the solution to a system of equations defined as above gave negative estimates for a. When this occurred, $\hat{D}_{24}$ and $\hat{D}_{93}$ were used to solve for b and c with a assumed to be zero.

Based on data for stands at first thinning, the following regressions were developed:

Table 6.--Summaries of deviations for quadratic mean (D_q), minimum (D_m), and maximum (D_x) diameter for unthinned stands.

Deviations[1/]	Percent of Cases
----inches----	
$\Delta(D_q)$:	
-0.5 to +0.5	78
-1.0 to +1.0	99
Average = +0.13	
$\Delta(D_m)$:	
-1.0 to +1.0	70
-2.0 to +2.0	90
Average = 0.60	
$\Delta(D_x)$:	
-1.0 to +1.0	82
-2.0 to +2.0	93
Average = +0.20	

[1/] $\Delta(y)$ = (observed y) - (predicted y)

$$D_{24a} = -0.6617 + 0.2026\ D_{24b} + 0.8064\ D_{qb} + 1.3855\ B_r \quad (6)$$

$$R^2 = 0.90 \qquad s_{y.x} = 0.60$$

$$D_{63a} = 0.9605\ D_{63b} + 0.0212\ A + 0.8032\ B_r \quad (7)$$

$$R^2 = 0.99 \qquad s_{y.x} = 0.26$$

$$D_{93a} = -0.1044 + 1.0967\ D_{93b} - 0.0953\ D_{qb} + 0.2890\ B_r \quad (8)$$

$$R^2 = 0.99 \qquad s_{y.x} = 0.21,$$

where D_{pa} = p'th percentile after thinning,
D_{pb} = p'th percentile before thinning,
D_{qb} = D_q before thinning, all in inches,
A = age in years,
and B_r = basal area removed as a proportion of basal area before thinning.

None of the distributions generated by this system were declared significantly different from the observed and 91% of the cases had $\Delta(D_q)$ within ±0.5 inches (Table 7).

Based on 825 cases where a stand was thinned one or more times and remeasured after some growth interval, the following regressions were fitted:

Table 7.--Summaries of deviations for quadratic mean (D_q), minimum (D_m), and maximum (D_x) diameter for predicting distributions left immediately after first thinning.

Deviations[1]	Percent of Cases
----inches----	
$\Delta(D_q)$:	
-0.5 to +0.5	91
-1.0 to +1.0	98
Average = 0.09	
$\Delta(D_m)$:	
-1.0 to +1.0	69
-2.0 to +2.0	86
Average = 0.12	
$\Delta(D_x)$:	
-1.0 to +1.0	86
-2.0 to +2.0	96
Average = -0.07	

[1] $\Delta(y)$ = (observed y) - (predicted y)

$$D_{24e} = 0.4089 + 1.0314\ D_{24s} - 0.0289\ A - 0.0048\ B_s + 0.0101\ S + 0.1211\ t \qquad (9)$$

$$R^2 = 0.96 \qquad s_{y.x} = 0.41$$

$$D_{63e} = 0.5334 + 1.0365\ D_{63s} - 0.0358\ A - 0.0049\ B_s + 0.0075\ S + 0.1845\ t \qquad (10)$$

$$R^2 = 0.98 \qquad s_{y.x} = 0.28$$

$$D_{93e} = 0.5135 + 1.0181\ D_{93s} - 0.0375\ A - 0.0045\ B_s + 0.0098\ S + 0.2279\ t \qquad (11)$$

$$R^2 = 0.98 \qquad S_{y.x} = 0.34$$

where D_{pe} = p'th percentile at the end of the growth period,
D_{ps} = p'th percentile at the start of the growth period (after thinning if thinned), all in inches,
A = age in years,
B_s = basal area in square feet per acre at the start of the growth period,
S = base-age-25 site index in feet,
and t = length of the growth period in years.

Just as was the situation with the equations for distributions after first thinning, none of the predicted distributions based on equations (9)-(11) were declared significantly different with the Kolmogorov-Smirnov goodness of fit test. In 89% of the cases, predicted quadratic mean diameter was within ±0.5 inch of the observed (Table 8).

Table 8.--Summaries of deviations for quadratic mean (D_q), minimum (D_m), and maximum (D_x) diameter for predicting distributions after growth.

Deviations[1]	Percent of Cases
----inches----	
$\Delta(D_q)$:	
-0.5 to +0.5	89
-1.0 to +1.0	98
Average = 0.10	
$\Delta(D_m)$:	
-1.0 to +1.0	59
-2.0 to +2.0	81
Average = 0.59	
$\Delta(D_x)$:	
-1.0 to +1.0	83
-2.0 to +2.0	94
Average = -0.20	

[1] $\Delta(y)$ = (observed y) - (predicted y)

Converting from Percentiles to Weibull Parameters

As was indicated above, predicted values for D_{24}, D_{63}, and D_{93} together with equation (2) define a system of 3 equations with the parameters <u>a</u>, <u>b</u>, and <u>c</u> as unknowns:

$$D_{24} = a + b[-\ln(0.76)]^{1/c} \qquad (12)$$

$$^{1/}\ D_{63} = a + b[-\ln(0.37)]^{1/c} \qquad (13)$$

$$= a + b$$

$$D_{93} = a + b[-\ln(.07)]^{1/c} \qquad (14)$$

These can be combined to give an expression in <u>c</u> only:

$$\frac{D_{63} - D_{24}}{D_{93} - D_{63}} = \frac{1 - (.2744368)^{1/c}}{(2.6592600)^{1/c} - 1},$$

$$\text{or } \lambda(D_{24}, D_{63}, D_{93}) = \gamma(c), \qquad (15)$$

---

[1] The exact value for p in the case of D_{63} is $100(1-e^{-1})$ where "e" is the base of the natural logarithms. To 5 decimals, p = 63.21206.

where the definitions of $\lambda(D_{24}, D_{63}, D_{93})$ and $\gamma(c)$ are implied by the first expression in (15) above. Thus, to calculate predicted values for a, b, and c, $\lambda(D_{24}, D_{63}, D_{93})$ is computed with the predicted percentiles and (15) solved for c. Then b is obtained with the equation

$$b = (D_{63} - D_{24})/[1 - (0.2744368)^{1/c}], \qquad (16)$$

which is derived from (12) and (13) above. Lastly, a can be obtained from either (12), (13), or (14); equation (13) obviously being the easiest to solve.

The function $\gamma(c)$ is quite well behaved (Table 9) and equation (15) can be solved easily and cheaply on a computer with standard methods of numerical analysis. However, to facilitate desk calculator solutions of (15), linear interpolation in table 9 is recommended.

Table 9.--Values for $\gamma(c) = [1 - (.2744368)^{1/c}]/[(2.6592600^{1/c} - 1]$ with c = 0.25 to 12.0 by 0.25.

c	$\gamma(c)$	c	$\gamma(c)$	c	$\gamma(c)$
0.25	0.0203	4.25	1.0137	8.25	1.1526
0.50	0.1523	4.50	1.0287	8.50	1.1572
0.75	0.3061	4.75	1.0423	8.75	1.1616
1.00	0.4373	5.00	1.0547	9.00	1.1658
1.25	0.5431	5.25	1.0661	9.25	1.1697
1.50	0.6283	5.50	1.0765	9.50	1.1735
1.75	0.6976	5.75	1.0861	9.75	1.1771
2.00	0.7549	6.00	1.0950	10.00	1.1805
2.25	0.8028	6.25	1.1033	10.25	1.1838
2.50	0.8434	6.50	1.1109	10.50	1.1869
2.75	0.8783	6.75	1.1181	10.75	1.1898
3.00	0.9084	7.00	1.1248	11.00	1.1927
3.25	0.9348	7.25	1.1310	11.25	1.1954
3.50	0.9581	7.50	1.1369	11.50	1.1980
3.75	0.9787	7.75	1.1424	11.75	1.2005
4.00	0.9972	8.00	1.1476	12.00	1.2029

AN EXAMPLE

As an example of the application of these models, equations (3)-(5) and (6)-(8) were used to determine the parameters of the diameter distribution before and after thinning (fig. 1a) of a 15-year-old plantation with 500 trees per acre and site index of 60 feet at age 25. A light thinning from below was applied by which basal area was reduced by 15% from 92 to 79 square feet per acre, and 394 trees per acre were left (table 10). This amounted to 150 to 180 cu. ft. of merchantable wood (4" o.b. top) per acre removed. The shift in the diameter distribution is obvious (fig. 1a).

To obtain diameter distributions at later ages, a prediction of mortality was necessary. Since an analysis of the full data set for mortality relationships is not complete at this time, the equation given by Clutter and Jones (1980) based on first-remeasurement data was used. In addition, their site index equation was solved for dominant height in order to predict D_{93u} with equation (5). Their mortality equation predicts about 1.2% mortality per year for the example stand which gives 371 trees at age 20 when the second thinning was imposed. Equations (9)-(11) were used to predict stand structure at age 20 when another 15% basal area removal was effected. The structure before and after the second thinning is shown in figure 1b. The same process was applied to obtain stand structure at ages 25 and 30 with a third thinning imposed at age 25 (fig. 2).

Stand structure at age 30 from the above thinned example was compared with structures projected for two unthinned stands (figure 2b and table 10). One of these unthinned stands was started from 500 trees per acre at age 15, as was the thinned stand; and mortality was predicted with the Clutter and Jones (1980) equation which resulted in 399 trees per acre at age 30. The other unthinned stand had 239 trees per acre at age 30, the same as the thinned stand.

The contrast between the two unthinned stands and the thinned stand at age 30 (fig. 2b) is quite reasonable. In this case, the thinned stand does not have significantly more trees in the large diameter classes (≥9 inches) than an unthinned stand of the same density. This is certainly logical in view of the type of thinning carried out. Although we have not completed an analysis to test it, a conjecture that more of the larger trees in the thinned stand will yield good quality sawlogs and veneer bolts is undoubtedly supportable.

CONCLUSIONS

Previous work with the Weibull model for unthinned plantations where equations to predict a, b, and c were developed have given rejection rates of 14% or greater with the Kolmogorov-Smirnov test. Deviations within ±0.5 inches for quadratic mean diameter have ranged from 80 to 90% (Clutter and Belcher, 1978; Smalley and Bailey, 1974a and 1974b; Lohrey and Bailey, 1976). Our tests on these data from thinned slash pine plantations lead to no rejections and 90% of the deviations were within ±0.5 inches. We therefore conclude that smooth distribution functions, such as the Weibull, can be applied quite well in modeling diameter distributions of thinned conifer plantations.

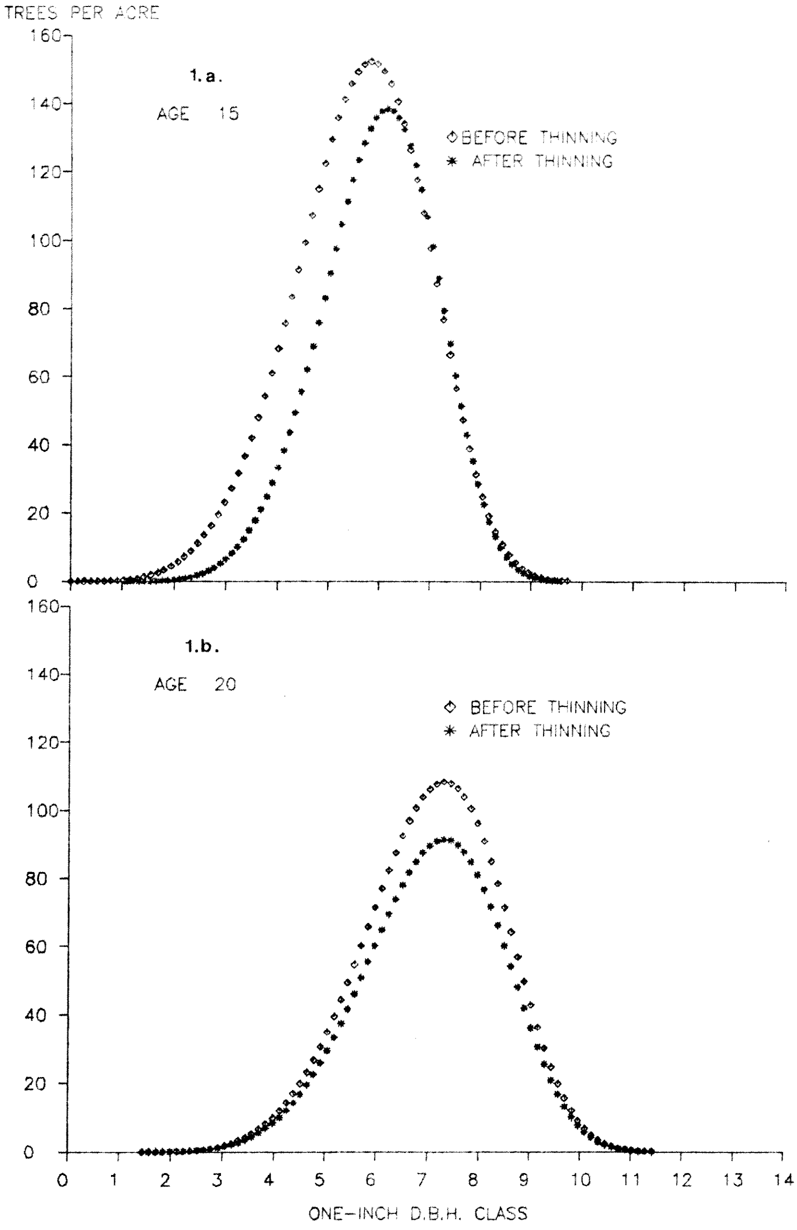

Figure 1.--Diameter distributions at ages 15 and 20. Site index is 60 feet, 15% basal area removed in thinnings, and trees per acre at age 15 was 500.

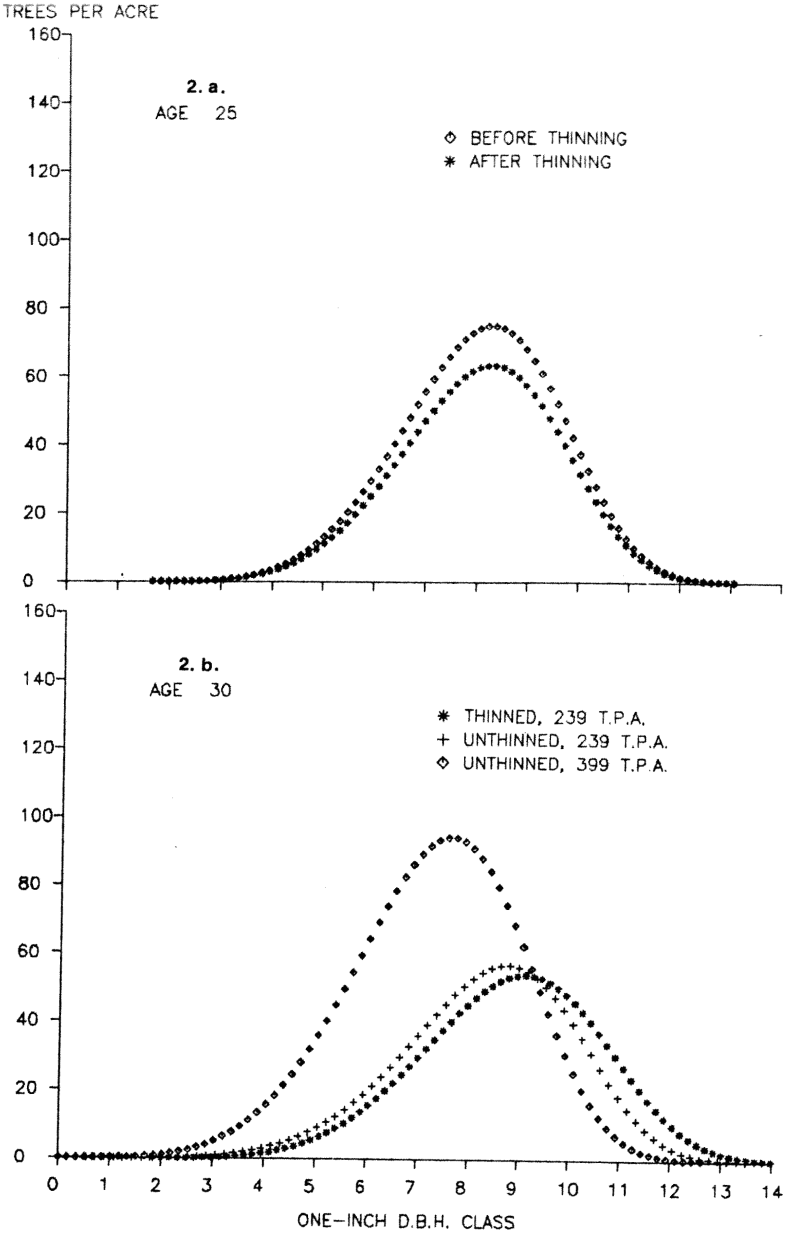

Figure 2.-- Diameter distributions at age 25 and 30. One unthinned stand at age 30 has the same density as the thinned and the other started with the same density at age 15.

Table 10.--Typical stand structure development to age 30 for a slash pine plantation on site index 60 (base age 25) having three periodic thinnings, compared with structures of two similar but unthinned plantations.

Age (years)	Trees per acre	Basal Area	Percentiles D_{24}	D_{63}	D_{93}	Weibull Parameters a	b	c	Mean D.b.h.
Thinned Plantation									
	-number-	sq. ft.	------inches------			--inches--			inches
15[1/]	B: 500	92	4.7	6.2	7.4	0.0	6.1	4.947	5.8
	A: 394	79	5.2	6.4	7.6	1.1	5.3	4.946	6.1
20	B: 371	105	6.1	7.6	9.0	1.4	6.2	4.765	7.2
	A: 313	89	6.1	7.6	9.0	1.4	6.2	4.765	7.2
25	B: 297	109	6.9	8.6	10.3	1.7	7.0	4.662	8.2
	A: 251	92	6.9	8.6	10.3	1.7	7.0	4.662	8.2
30	239	106	7.6	9.5	11.3	1.8	7.7	4.583	9.0
Unthinned Plantation									
30[2/]	399	123	6.2	8.5	9.7	0.0	8.0	5.017	7.5
30[3/]	239	95	7.2	9.5	10.7	0.0	9.0	5.751	8.5

[1/] First thinning at age 15 in stand of 500 trees per acre; "B" and "A" denote before and after each merchantable thinning which removed 15% of the standing basal area.

[2/] Grown without thinning from an original stand of 500 trees per acre at age 15.

[3/] Grown without thinning but having the same number of trees per acre at age 30 as the thinned stand above.

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A DIAMETER DISTRIBUTION METHOD USEFUL IN COMPATIBLE GROWTH AND YIELD MODELING OF THINNED STANDS[1]

M. R. Strub[2]

D. P. Feduccia

V. C. Baldwin, Jr.

Abstract.--Two growth and yield forecasting techniques have been combined to develop equations that predict the change in diameter distribution in thinned loblolly pine (*Pinus taeda*) plantations. The equations are based on the concept of compatible growth and yield applied to a diameter distribution model for unthinned loblolly pine plantations. This produces a generalization of the unthinned equations that projects size distribution in thinned plantations. The forecasts are compared with stand tables from a thinned plot from a spacing-thinning study located at Merryville, Louisiana.

INTRODUCTION

Diameter distribution models have been used to forecast yield of unthinned plantations since their introduction by Bennett and Clutter (1965). Models in this paper are based on a recent application of this technique by Feduccia and others (1979). Feduccia assumes that the frequency of tree dbh is described by the Weibull function,

$$\text{Proportion of trees} < D = 1 - e^{-\left(\frac{D-\alpha}{\beta}\right)^{\gamma}},$$

where α, β, and γ are Weibull parameters and D is an arbitrary diameter limit. All trees in the plantation are larger than α, β is a scale parameter that controls the range of diameters and γ is a shape parameter that controls the skew of the diameter distribution. The parameters are predicted from the stand variables age from planting, Ap, average height of the dominant and codominant trees, Hd, and number of surviving trees per hectare, Ts. Three prediction equations with the same functional form but different coefficients (bo, b1, b2 and b3) are used to predict the three parameters, namely

$$\alpha,\beta \text{ or } \gamma = bo + b1 \log(Ap) + b2 \log(Hd) + b3 \log(Ts).$$

These equations can be generalized to forecast size distribution of thinned plantations by applying compatible growth and yield concepts developed by Clutter (1963) and later refined by Moser and Hall (1969). Moser and Hall defined the first derivative of yield, Y(A), with respect to age, A, as growth rate, y(A), namely

$$dY(A)/dA = y(A).$$

The change in yield or growth over the period

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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Ao to A1, ΔY(Ao to A1), is

$$\Delta Y(\text{Ao to A1}) = \int_{A0}^{A1} y(A)dA = Y(A1) - Y(A0)$$

These concepts can be generalized to describe changes in Weibull parameters.

GROWTH OF WEIBULL PARAMETERS

The growth rate of a Weibull parameter can be defined in the same way Moser and Hall described growth of forest stands. The growth rate, p(A), of the Weibull parameter, P(A), is

$$dP(A)/dA = p(A).$$

The change in the Weibull parameter or growth over the period A0 to A1, ΔP(A0 to A1) is

$$\Delta P(\text{A0 to A1}) = \int_{A0}^{A1} p(A)dA = P(A1) - P(A0).$$

Applying this to the equations from Feduccia and others (1979) results in

$$\Delta P(\text{A0 to A1}) = b1[\log(A1)-\log(A0)] +$$

$$b2[\log(H1) - \log(H0)] + b3[\log(T1) - \log(T0)],$$

where H0 and H1 are dominant heights at A0 and A1 and T0 and T1 are trees per hectare at A0 and A1. This set of equations can be used to update inventory information. If H0, T0, and the Weibull parameters are known from measurements of an existing stand and H1 and T1 are forecast from site index curves and survival curves, Weibull parameters at A1 can be forecast by adding ΔP(A0 to A1) to the Weibull parameters at A0. These forecast Weibull parameters can be used to describe the stand table at A1.

GROWTH OF WEIBULL PARAMETERS IN THINNED PLANTATIONS

The same set of equations can be used to forecast stand tables in thinned plantations. The only difference is that T0 and T1 are reduced due to the thinning. This results in greater shifts to the right of the stand table, and hence faster diameter growth in thinned stands. This procedure for forecasting stand tables was compared with data from three thinning studies located in Louisiana.[1/] This comparison indicated that the thinned plantations grew slightly faster than the equations forecast. A correction factor based on age at the first thinning intervention, TA, and residual basal area per hectare for the first thinning, TB, was added to the growth equation for the α parameter to account for the difference in estimated and observed diameter growth rates. The correction factor was determined by regressing the difference between observed and estimated α parameter on a set of stand variables including TA and TB. The final form of the correction factor, CF(A0 to A1), is

$$CF(\text{A0 to A1}) = [1.7541 - 0.0033148 \cdot TA \cdot TB] \cdot$$

$$[A1 - A0].$$

Use of the correction factor results in slightly faster growth rates in plantations thinned heavily at young ages.

The use of this procedure for estimating growth of thinned stands is illustrated with data from plot 54 of the Merryville Thinning Study.[2/] The plot was planted at a 3 x 3 meter spacing and is site index 21 meters on a 25 year base. Figure 1 shows the stand table and Weibull diameter distribution for the plot at 17 years after planting and thinning to 14 square meters per hectare. The parameters of the diameter distribution were estimated with maximum likelihood procedures from the stand table data.

[1/] Unpublished Forest Service progress reports describe these three studies.

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[2/] Data from this study is described in Feduccia, D. P. and W. F. Mann, Jr. 1975. Op. Cit.

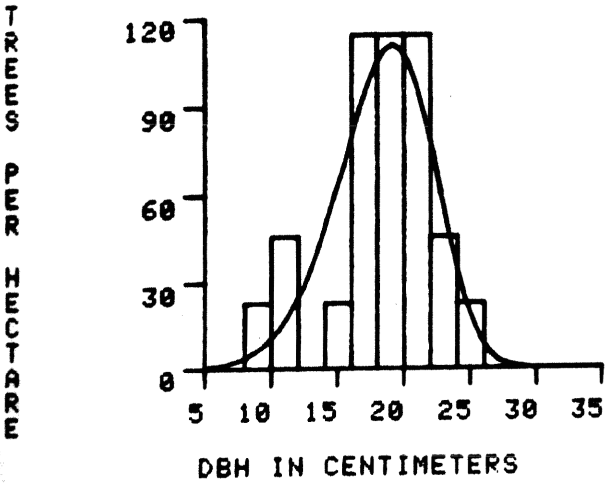

Figure 1.--Stand table and diameter distribution 17 years after planting and thinning to 14 m^2/ha.

The Weibull parameter growth equations were used to forecast the diameter distribution at 22 years from planting. The results of this forecast and the observed stand table are presented in Figure 2.

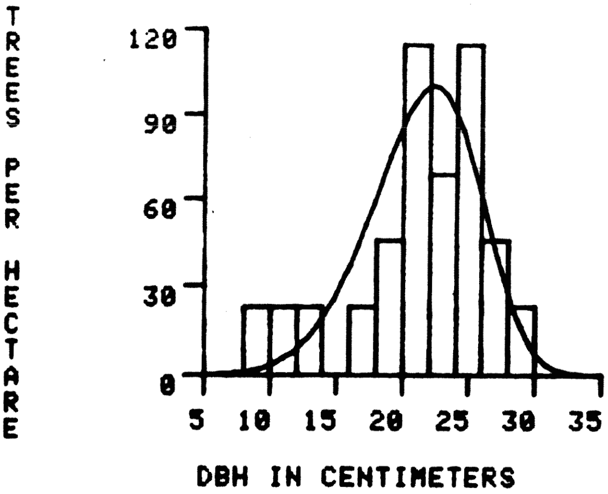

Figure 2.--Stand table and diameter distribution 22 years after planting.

The forecasting technique worked reasonably well on this plot.

SUMMARY

Equations for projecting changes in diameter distribution in thinned and unthinned plantations have been developed. When used in combination with site index curves, survival curves, individual tree volume equations and height from dbh curves they can be used to estimate yield and size distribution of various thinning regimes and to update forest inventory information.

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A THINNING RULE FOR SLASH PINE PLANTATIONS ON A MEDIUM SITE[1]

F. Thomas Lloyd and Earl P. Jones, Jr.[2]

Abstract.--Target, after-thinning, residual densities that produce near maximum periodic growth of slash pine plantations are determined for medium sites with an average height at age 25 of 63 feet. This was done by fitting net 5-year growth (in pounds of dry wood per acre) to the corresponding values of Stahelin's percent stocking obtained from unthinned stands covering a wide range of densities. This approach is based on the assumption that the growth of the thinned stand will quickly recover to that of an unthinned stand of the same percent stocking. The stand ages at which thinnings should be made were also established. This age is defined as the point where the annual accretion of what would be the yield from a first thinning begins to decrease.

INTRODUCTION

Growing space is a leading factor in controlling the growth rate of individual trees. The choice of planting spacing and the timing and intensity of thinning offers foresters who manage slash pine plantations two methods of controlling this determinant of tree growth. Much has been published about the effects of the planting spacing on yield, but very little on the interrelationship between initial spacing and subsequent thinning schedules.

A defendable strategy for pulpwood production is to maximize total net growth (i.e., growth of surviving trees minus mortality) from a site over the rotation. This is accomplished by thinning as frequently as is economically possible in such a way as to salvage potential mortality and maintain the stand at near full occupation of the site. The problem is that measurement of net growth is both costly and subject to large error. What we do then is calibrate more easily observed or measured stocking attributes with net growth and use the stocking measure as the control variable. Stahelin's (1949) stocking percent is used in this study because it is easily obtained by using an angle prism, does not depend on age and site quality, and has been successfully applied to thinned stands of natural slash pine (Gruschow and Evans 1959). The goals of this work are 1) to estimate target residual densities and ages of the first thinnings for plantations resulting from a wide range of planting densities on a medium slash site and 2) to hypothesize stocking guides as to when to initiate first thinnings in these slash pine plantations.

SOURCE OF DATA

These data come from a study established by the Southeastern Forest Experiment Station in 1952 on the Holt Walton Experimental Forest in the middle Coastal Plain region of Georgia. Seedlings were planted at 8 spacings: 15 x 15, 7.5 x 15, 10 x 10, 6 x 12, 8 x 8, 5 x 10, 6 x 8, and 6 x 6 feet. Three-quarter-acre spacing plots were randomly assigned in each of two complete blocks, and the entire study was installed in an old field which had last been cultivated the previous year. Harms and Collins (1965) observed that with good soil moisture conditions and care in handling and planting the seedlings, 97 percent survival at age 4 resulted--much better than average, with each spacing plot as fully stocked as could be expected. Starting at age 10, measurements for each plot consisted of a complete diameter tally and a random sample of heights on at least 20 trees distributed evenly over the diameter classes. These measurements were taken annually from age 10 through age 22 and again at age 25.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

[2] Authors are Research Foresters, USDA Forest Service, Forestry Sciences Laboratory, Charleston, SC 29407, and Southern Forest Fire Laboratory, Macon, GA 31208, respectively.

PROCEDURES

The diameter and height measurements on the two plots for each spacing were combined into a composite plot and converted to yield (in pounds) of total stem dry weight (i.b.) per acre (Queen and Pienaar 1977). Weight was used instead of volume because we wanted total yield to a 2-inch diameter class and a volume table for this range of diameters was not available when the analysis started, and because the use of pulpwood weight is extensive. These computations resulted in 112 stand tables and yield observations (eight spacings each measured 14 times). Each spacing yielded nine 5-year net growth values for the growth periods 10 to 15, 11 to 16,..., 17 to 22, and 20 to 25 years. We chose the 5-year growth period because it represents the practical minimum time between thinnings. Also, the coefficient of variation for growth becomes prohibitively large for periods shorter than five years. The first step was to relate these increments of net periodic growth to some measure of stocking.

Gruschow and Evans (1959) successfully used Stahelin's (1949) percent stocking as a predictor of periodic growth of thinned natural stands of slash pine. They chose not to use basal area alone because at theoretical full stocking it varies widely with site and age. In addition, because of our range of 1000 seedling per acre at planting, we wanted a stocking measure that reflected increasing basal area for the same stocking level as the number of trees per acre decreased. Figure 1 illustrates how these data approach and then follow Stahelin's 100 percent curve for the two densest spacings.

The decision of when to thin depends on the target stocking because a greater percentage of volume is removed to obtain the lower residual densities. Therefore, the first step in this analysis concerned establishing a range for residual stocking that produced near maximum periodic growth. This was done by combining the data from all spacings and then studying the relation of 5-year net growth to Stahelin's (1949) percent stocking. This is based on the assumption that periodic growth of a thinned stand will be close to that of an unthinned stand with the same percent stocking. A point of maximum growth was expected to be contained in these data because of the wide range of planting densities.

The stand age at the first thinning from below varies with planting spacing and, as discussed earlier, probably with the target residual stocking. We estimated this stand age as that point in stand development where the annual increase in the weight of the first thinning begins to decline. We approximated the yields for the first thinning at each age by removing trees one at a time from the observed stand tables until the target residual density was reached. The onset of declining thinning yield is estimated as the point of inflection for a model expressing the above defined thinning yield as a function of stand age. These removed yields are only approximations to real thinnings because diameter distributions do not contain information about spacial distributions of the residual stands, but because we are removing the smallest trees, the outcome of actual thinnings should not differ greatly.

For a given planting spacing, the age of maximum accretion in the first thinning yield will increase with decreasing plantation survival, so although these ages can be used to compare the timing of the first thinning under the uniform conditions of this study, they do not offer useful guidelines for field applications. However, if either percent stocking or basal area values corresponding to these ages are stable, then a general thinning rule is suggested. This is our approach to satisfying the second objective.

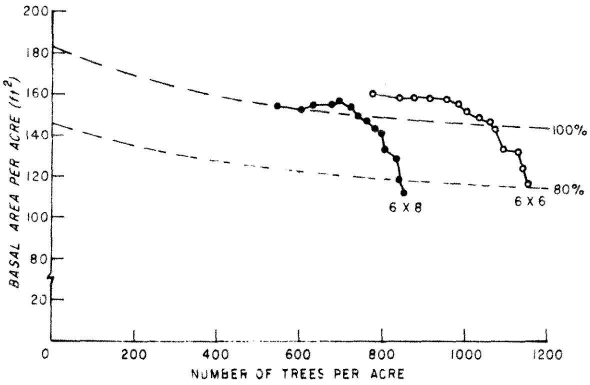

Figure 1.--The basal area and number of trees per acre for the 6 x 8 and 6 x 6 spacings plotted with Stahelin's 100 and 80 percent stocking curves.

RESULTS

The nine periodic growth and percent stocking values were combined for the eight spacings (72 observations) and plotted (fig. 2, see last page). The mean relationship was adequately described with the quadratic equation: periodic growth = $5332.47 + 833.556$ (% stocking) $- 6.86355$ (% stocking)^2. The R^2 value of the model is 0.44. The large variation is explained in part by the inherent variability in growth due to measurement error, as well as variation resulting from the spacing plots. Maximum net growth from this equation occurs at 60 percent stocking which (as was anticipated) is inside the observed stocking range. The following predictions from this equation (rounded to the nearest 100 lbs.)

illustrate the declining rate of periodic growth for stocking above 80 percent:

Percent stocking	Lbs/acre
40	27,700
50	29,900
60	30,600
70	30,000
80	28,100
90	24,800
100	20,100
110	14,000

Gruschow and Evans observed that the rate of increase for percent stocking was low in the lightly and heavily stocked stands and tended to be greatest at the 40 to 50 percent levels. This observation was substantiated by our data, so residual levels of 60 percent, 50 percent, and 40 percent stocking were used to investigate the question of when to thin. As with Gruschow and Evans' work with natural slash pine, we expect the percent stocking levels for maximum growth to be higher for plantations on better sites, but were unable to investigate site effects in this study.

The estimated ages of thinning for these plots are shown in table 1 for residual stockings of 60, 50, and 40 percent. The growth rate of thinning yield culminates before age 10 for the two densest spacings. The effect of planting spacing on age of first thinning is large, while the effect of residual stocking on thinning age is only a 1-year reduction for each 10 percent reduction in residual stocking. The residual basal areas are not constant, but range from 10 to 15 ft.^{2} across the initial spacing range. This outcome fits Reineke's (1933) result which shows basal area for a given stocking level to be proportional to the inverse of number of trees per acre. The standing basal areas and corresponding percent stockings at the predicted thinning ages for residual stockings of 60, 50, and 40 percent are shown in table 2. The average standing basal area values suggest to thin to 60, 50, and 40 percent stocking when basal area reaches 119, 112, and 107 ft.^{2}, respectively.

We have included raw data in table 3 for the person interested in viewing the analysis from other angles. The problem of extreme variation in annual growth is clear if yearly differences are computed, for by using these differences it is difficult to determine with any degree of certainty the optimum thinning age as defined. However, cubic functions of time using all thinning yields for a given spacing and residual percent stocking have R^2's greater than 0.99, and therefore give precise estimates of average net growth for any age in the observed age range and good estimates of the point of inflection. The sums (i.e., total yields) of the pairs of numbers for each age and planting spacing is the same (within rounding error) for all residual percent stockings, but the thinning component accounts for a larger percent of the total as residual stocking decreases. The magnitude of thinnings in table 3 also gives information about the economic feasibility of first thinnings at various ages.

Table 1.--Estimated age for thinning in eight planting spacings to achieve three selected residual stock densities expressed as Stahelin's percent stocking

Planting spacing	Thinning age	Trees per acre at thinning	Basal area after thinning	Trees after thinning
ft	yr	no	ft^2	no
RESIDUAL DENSITY: 60 PERCENT STOCKING				
15 x 15[1]	>25	<161	>101	
7.5 x 15	19	339	97	240
10 x 10	17	367	96	269
6 x 12	16	507	94	343
8 x 8	13	642	92	421
5 x 10	12	819	90	538
6 x 8[1]	<10	>850	<90	
6 x 6[1]	<10	>1152	<87	
RESIDUAL DENSITY: 50 PERCENT STOCKING				
15 x 15[2]	21	165	84	128
7.5 x 15	17	347	81	217
10 x 10	16	374	80	223
6 x 12	14	520	78	303
8 x 8	12	651	77	366
5 x 10	11	826	75	482
6 x 8	<10	>850	<75	
6 x 6	<10	>1152	<72	
RESIDUAL DENSITY: 40 PERCENT STOCKING				
15 x 15[2]	21	165	67	97
7.5 x 15	16	349	64	173
10 x 10	15	376	64	182
6 x 12	13	523	63	250
8 x 8	11	652	61	302
5 x 10	11	826	60	372
6 x 8	<10	>850	<60	
6 x 6	<10	>1152	<58	

[1] Annual growth rate in thinning yield culminates outside the observed age range (10 to 25 years).

[2] Values supported by limited number of data points.

Table 2.--The age, basal area, and percent stocking before thinning for five planting spacings to be thinned to residual densities of 60, 50, and 40 percent stocking

Planting spacing[1/] (ft)	Residual Percent Stocking								
	60			50			40		
	Thinning age	Basal area	Stocking	Thinning age	Basal area	Stocking	Thinning age	Basal area	Stocking
	yr	ft^2	percent	yr	ft^2	percent	yr	ft^2	percent
7.5 x 15	19	118.9	74	17	109.5	68	16	105.1	65
10 x 10	17	117.7	73	16	114.7	72	15	109.1	68
6 x 12	16	119.3	76	14	112.4	72	13	105.9	68
8 x 8	13	120.1	78	12	114.1	74	11	104.3	68
5 x 10	12	119.3	79	11	110.6	74	11	110.6	74
Mean		119	76		112	72		107	69

[1/] The 15 x 15, 6 x 8, and 6 x 6 spacings are not included because maximum annual growth rate in thinning yield occurs outside observed age range of 10 to 25 years.

CONCLUSIONS

Maximum periodic growth in total stem wood (i.b.) on average slash pine sites (63 feet, base age 25) is maintained by thinning when basal area reaches 119, 112, and 107 $ft.^2$ for residual stockings of 60, 50, and 40 percent, respectively. These guides should apply for several subsequent thinnings, but we are not able to test this assertion with these data. The choice of residual stocking will depend on how frequent subsequent thinnings will be made and how much is needed to be economically feasible. The 40-percent residual stocking leaves a light basal area, but the net periodic growth following this intensity of thinning is 90-percent of the maximum and the growth is increasing. Another point illustrated by these data is that target residual basal area is not constant but, rather, increases as the residual number of trees decreases. As expected, the age at time of thinning decreases as planting density increases, but will vary with plantation survival, so the decision when to thin should be determined by periodically checking standing basal area.

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Table 3.--Weight of yield removed in thinning (lower value) and left in residual stand (upper value) for theoretical thinnings applied at ages 10 through 22 and age 25, in eight spacings reduced to residual densities of 60, 50, and 40 percent stocking

Age (years)	Planting spacing (feet)							
	15x15	7.5x15	10x10	6x12	8x8	5x10	6x8	6x6
	100 pounds							
	RESIDUAL DENSITY: 60 PERCENT STOCKING							
10	147	247	264	300	304	291	307	291
	0	0	0	0	6	39	70	85
11	182	289	312	329	323	324	325	314
	0	0	0	0	35	63	98	118
12	237	373	387	387	369	358[1]	368	347
	0	0	0	35	83	102	150	163
13	272	411	438	417	402[1]	382	401	350
	0	0	7	47	110	119	177	170
14	343	497	491	459	459	424	448	408
	0	6	38	79	153	155	223	233
15	380	533	533	499	499	460	472	437
	0	29	62	103	182	176	249	256
16	430	569	567	514[1]	519	486	498	455
	0	41	99	120	213	209	272	277
17	470	593	586[1]	534	537	496	516	474
	0	66	115	137	234	222	284	298
18	543	637	619	562	561	534	545	508
	0	99	159	180	289	269	332	338
19	609	668[1]	661	607	594	565	580	519
	0	131	186	209	315	289	358	362
20	665	695	689	623	619	588	614	549
	0	154	227	216	337	303	371	375
21	702	714	711	647	654	612	643	571
	0	179	254	237	361	313	373	377
22	741	734	737	649	671	633	657	589
	0	200	248	250	343	297	373	388
25	830	792	785	728	736	683	715	624
	73	264	310	289	377	330	404	406
	100 pounds							
	RESIDUAL DENSITY: 50 PERCENT STOCKING							
10	147	247	264	271	257	245	258	248
	0	0	0	29	53	85	119	128
11	182	289	297	280	273	272[1]	273	264
	0	0	15	48	85	115	150	167
12	237	351	338	327	309[1]	302	310	291
	0	22	48	95	144	158	208	218
13	272	368	372	352	337	321	335	294
	0	43	73	112	175	179	243	226
14	343	422	413	385[1]	386	358	375	344
	0	81	116	153	226	221	296	297
15	380	449	447	422	421	385	396	369
	0	112	148	181	260	251	324	325
16	430	478	476[1]	433	438	407	419	385
	0	131	189	201	294	288	351	347
17	470	498[1]	495	448	454	417	435	399
	0	160	206	223	318	301	365	372
18	535	538	518	471	469	449	462	425
	8	198	260	271	380	353	415	421
19	572	563	554	510	496	476	485	437
	37	237	292	307	412	378	452	444
20	593	584	581	525	520	498	515	462
	71	265	336	314	436	393	470	463
21	617	600	599	544	551	517	540	480
	85	292	365	340	464	408	476	468
22	642	618	621	542	566	534	552	497
	99	316	365	357	448	395	479	480
25	701	668	657	610	617	577	605	530
	202	387	437	407	496	435	514	501

Table 3.--Continued

Age (years)	Planting spacing (feet)							
	15x15	7.5x15	10x10	6x12	8x8	5x10	6x8	6x6
	100 pounds							
	RESIDUAL DENSITY: 40 PERCENT STOCKING							
10	147	227	226	221	207	196	207	203
	0	20	39	79	103	133	170	172
11	182	242	240	228	224[1]	220[1]	221	212
	0	47	72	101	134	167	202	219
12	237	285	275	262	247	246	250	234
	0	88	112	160	206	214	269	275
13	272	297	300	286[1]	271	259	270	238
	0	114	145	179	241	241	308	282
14	332	341	330	312	311	287	303	279
	11	162	198	226	301	292	369	361
15	364	363	361[1]	341	341	310	320	300
	16	198	234	262	339	326	401	394
16	387	388[1]	385	349	352	328	340	309
	43	221	281	285	380	367	430	423
17	409	402	398	361	364	337	354	321
	61	256	303	311	408	381	447	450
18	438	432	419	380	377	365	372	342
	105	304	359	362	472	437	506	504
19	466	456	448	413	400	385	391	352
	143	343	398	404	509	470	547	529
20	481	472	468	424	422	402	414	374
	184	377	449	415	534	489	570	551
21	501	482	482	438	446	416	439	389
	201	411	482	446	569	509	577	559
22	518	496	502	436	459	431	448	406
	223	438	484	464	555	498	582	572
25	566	540	533	494	499	469	487	426
	337	515	561	523	614	543	632	605

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[1] Culmination of annual growth in thinning yield.

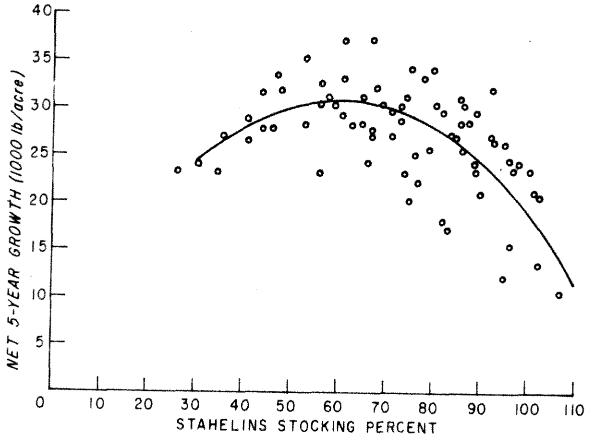

Figure 2.--Net 5-year growth in pounds for total stem dry weight and percent stocking points with the fitted quadratic function used to estimate the stocking level with maximum growth.

THINNING OPPORTUNITIES IN THE MIDSOUTH DURING THE 1980'S [1]

Charles E. Thomas

and

Mary S. Hedlund [2]

Abstract.--Plantation acreages in the Midsouth states have increased substantially during the past twenty years. Many of these acres will first reach commercial thinning age during the coming decade. Volumes, in pine only, on surveyed plantations indicate that serious attention must be paid to the incroachment of hardwoods if the optimistic expectations of published growth and yield estimates are to be realized. Volumes available from the portion of basal area greater than 60 square feet per acre are reported for surveyed locations in Mississippi.

Pine plantations, represent the hope and investment of the forest industry in the South. Other sources of timber are likely to be less productive and the product lower in quality. Considerable research resources have been devoted to describing and modeling the potential returns from intensive management of southern pine plantations. Unfortunately, most of these studies have been case studies emphasizing the better stands and their yields. In the past there has been little attempt to summarize the current state of plantations or to forecast production returns from existing stands over a wide area. Extensive area reports, such as the Forest Statistics of the U.S., 1977, made no attempts to delineate plantations from the total resource in the projections of timber supply. This paper attempts to give an overview of the acres and volumes likely to be available for commercial exploitation during the decade of the 80's in the seven Midsouth states.

Two aspects of the thinning opportunities will be examined. First, the acreages available - their distribution in time and geography - will be reported. Second, a sketch of the volumes and basal areas currently found in two specific states (Mississippi and Louisiana) will be reviewed. Based on the findings for example states, implications for the total resource of the Midsouth will be made.

Two sources of information were used to obtain the numbers of acres in plantations. The first is the U.S. Forest Service planting record. Each year the Forest Service releases a report showing acres of Forest Planting and seeding, by state and ownership class. The Midsouth still trails the Southeast in total acres planted with about 13 million acres as of fiscal year 1978. These planting record acreages (which are apt to overestimate true acreage) were compared to Southern Forest Experiment Station state inventory estimates of plantation acreage. Totals for all states and for the most recent 10-year interval in two states (Arkansas and Mississippi) were compared. The inventory findings alone are apt to be conservative. In the Midsouth the percentage of inventoried plantations to planted acres consistently shows between 70 and 80 percent of the plantation acreage reported in the planting records. Using a 20 percent reduction factor on the reported acres yields about 10 million acres of plantation in the seven states. This figure is about 33 percent of the 30 million acres of commercial forest presently considered pine type in the Midsouth.

Figure 1 illustrates the trend in plantings over a 25-year period. The trend for Midsouth states is somewhat different from that found in the Atlantic South. There a clear, nearly linear

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

[2] Research Forester and Mathematician, respectively, USDA-Forest Service, Southern Forest Experiment Station, New Orleans, La.

trend was established in the 50's. Even after the planting expansion during the Soil Bank Program, forest industry continued to increase the acres planted almost yearly. Our experience is different. After the brief expansion of planting during the late 50's, planting generally returned to the levels of the earlier part of the decade and remained at that level until the late 1960's. Total acres planted did not regularly exceed 400,000 per year until after 1970. At the state level the ages of plantations and acreages involved reveals an additional trend, the westward movement of forest management practices. Figures 2 - 5 show the onset of plantation establishment in several of the states. The oldest significant plantation acreages are those of Alabama, while the youngest are to be found in Texas and Arkansas. Only in the last five years have significant acres of plantation been established in Arkansas; these will not become suitable for commercial thinning until well into the 1990's.

The distribution of pine plantation is almost evenly divided in quarters among Alabama, Mississippi, Louisiana and the remaining four states of the Midsouth (Figure 6). For the next 10 years significant acreages suitable for thinning will come from the three Gulf Coast states.

In Louisiana there are many fewer acres of plantation inventoried than appear in the plantation record. During the ten year interval preceding the last inventory of the states forest less than 60% of the acres reported in the plantation record were discovered. This is a major departure from the pattern and percentage found in other midsouth states. A similar percentage of acres was found to have been established during the 10 year interval which began in 1952.

The next two figures (7 and 8) portray the ownership classes of commercial forest land in the region. Figure 7 is the overall ownership pattern indicating that industry owns nearly 20 percent of the 188 million acres reported in Forest Statistics of 1977. Seventy two percent of the acreage is owned by NIPF's (Non-Industrial Private Forest owners). In terms of plantations Forest Industry has nearly 50 percent of the reported acres planted, while only 38 percent of these acres are NIPF (Figure 8). (National Forest and other public owners represent less than 10 percent of the plantation acres). Many of the NIPF acres of plantation can be attributed to the Soil Bank Program. Forest survey data indicated significant shifts in land use between the two most recent surveys. Examination of the survey data did not reveal the specific disposition of Soil Bank era acres. Some certainly reverted to agricultural use, others remain in plantation. Because many of these Soil Bank-NIPF acres are now biologically ready to be thinned, disposition of these plantation acres will receive some attention in upcoming surveys.

The age distribution of existing pine plantations was determined from the planting data. Figure 9 shows percentage distribution of the data in 5-year age classes over the 10 million acres planted. Again the largest concentration is in the 20-year old class, those established under Soil Bank aegis. The second largest class is the recent planting (5-year-old class). Recall from Figure 4 that some of these young plantings are on poor shortleaf sites in the western part of the region and they will probably require longer to reach a commercially thinable density and volume.

The acreage of thinning opportunity in the Midsouth during the decade ahead is illustrated in Figure 10. Unlike the Southeastern area trend, a more pronounced upward trend in acres is noticeable. The number of acres planted in 1965 was less than 250,000, and when discounted for the acres observed in our state inventories this amounts to 200,000 acres that should be available for thinning. However, by the end of the period an annual thinning potential on nearly 600,000 acres could exist in the Midsouth. In the relatively short space of 10 years a three-fold expansion in the numbers of acres will require commercial thinnings, if the optimistic estimates of production under intensive management are to be realized. Such an increase could easily require technological or systems changes, thus it would be well to begin planning now for this development.

A second consideration in the region is the timing of the availability. A comparison of the years in which plantings began to increase noticeably shows clearly the movement east to west. It should not be surprising that significant acreages reach commercial thinning densities and volumes in Alabama and Mississippi earlier than in Louisiana, Texas, and Arkansas. This state-by-state trend does have something of a mitigating influence on the overall increases, but in some cases it could mean that the time to plan is already slipping past - as in Alabama. This problem of acrages available for thinning, deserves considerable attention by the states and private industry now.

Originally it was our intentions to estimate potential thinning volumes in pine plantations for the entire Midsouth. Time and data access limited

FIGURE 1. ACRES OF FOREST PLANTING

MIDSOUTH TOTALS BY OWNERSHIP

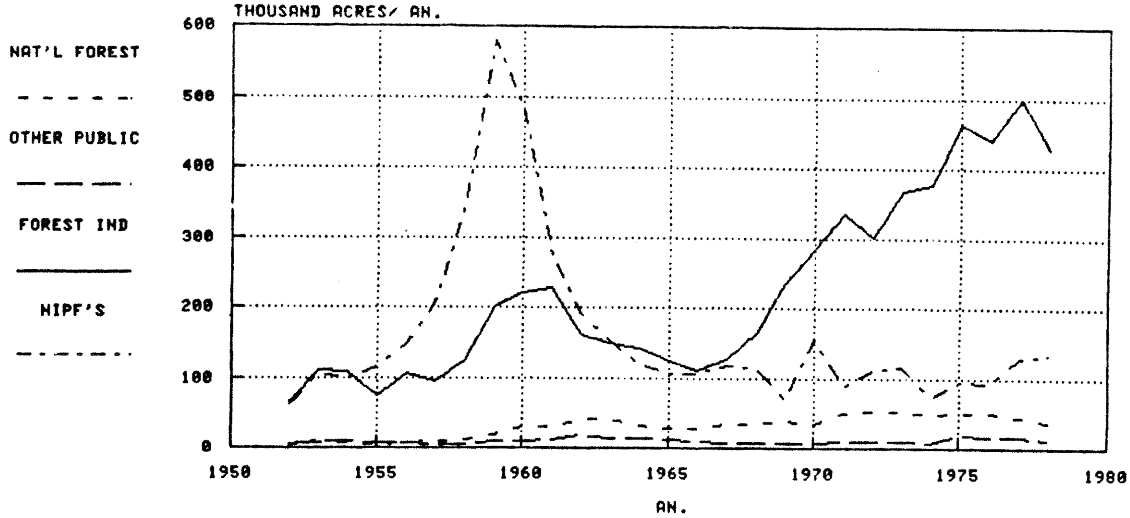


FIGURE 2. ACRES OF FOREST PLANTING

ALABAMA: BY OWNERSHIP

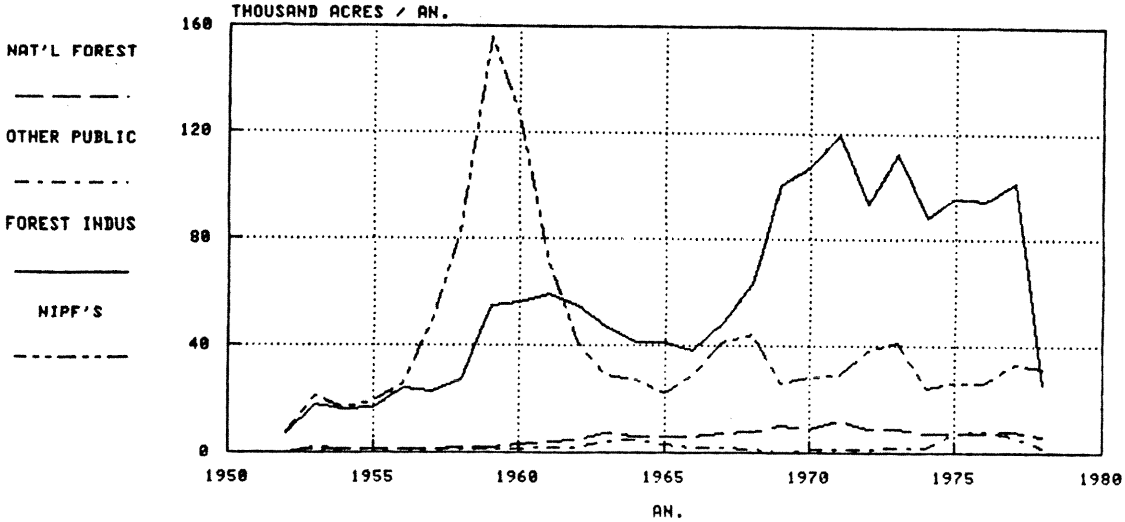


FIGURE 3. ACRES OF FOREST PLANTING

MISSISSIPPI: BY OWNERSHIP

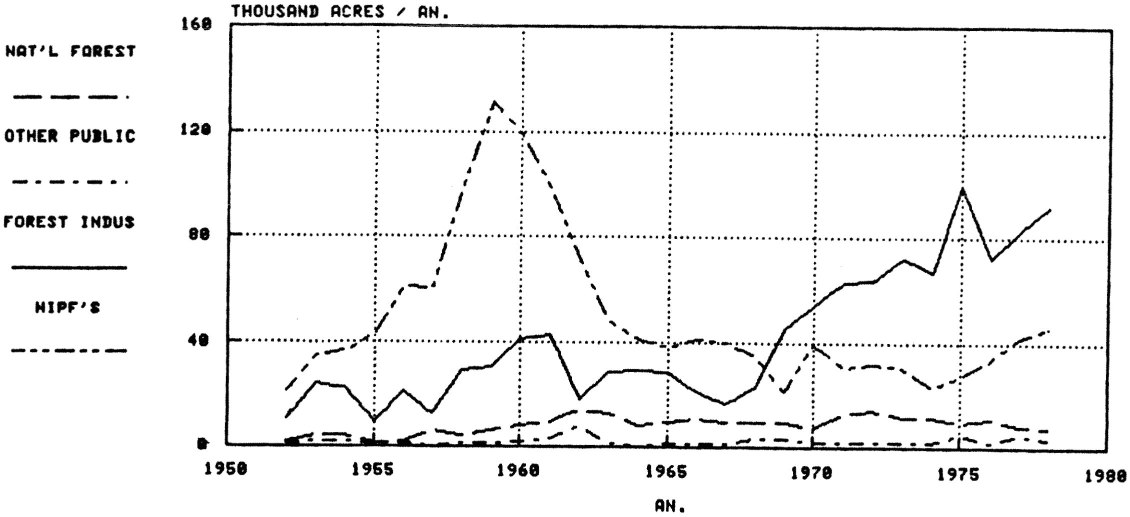


FIGURE 3a.ACRES OF FOREST PLANTING

Louisiana: by ownership class

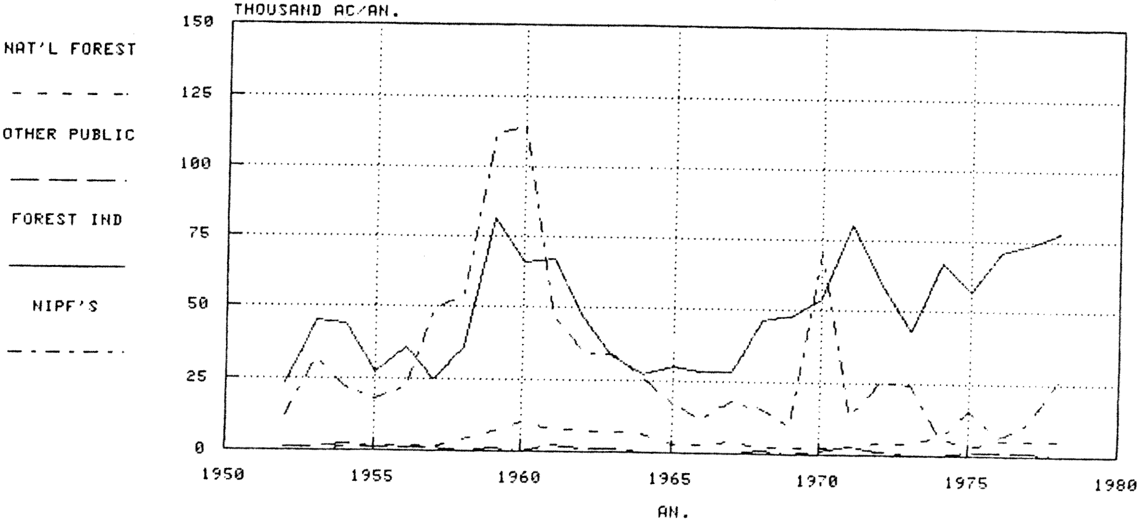


FIGURE 4. ACRES OF FOREST PLANTING

ARKANSAS: BY OWNERSHIP

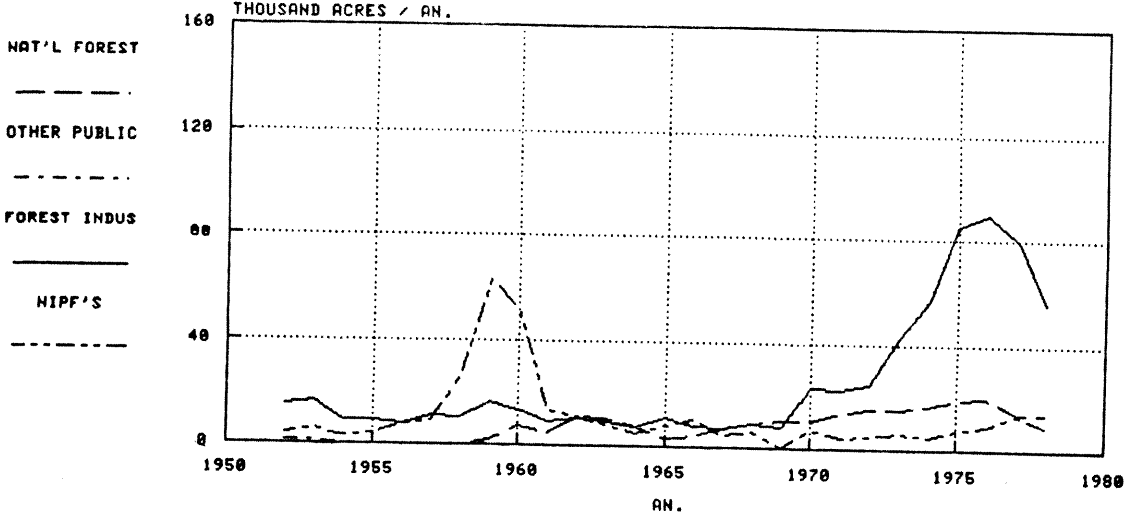


FIGURE 5. ACRES OF FOREST PLANTING

TEXAS: BY OWNERSHIP

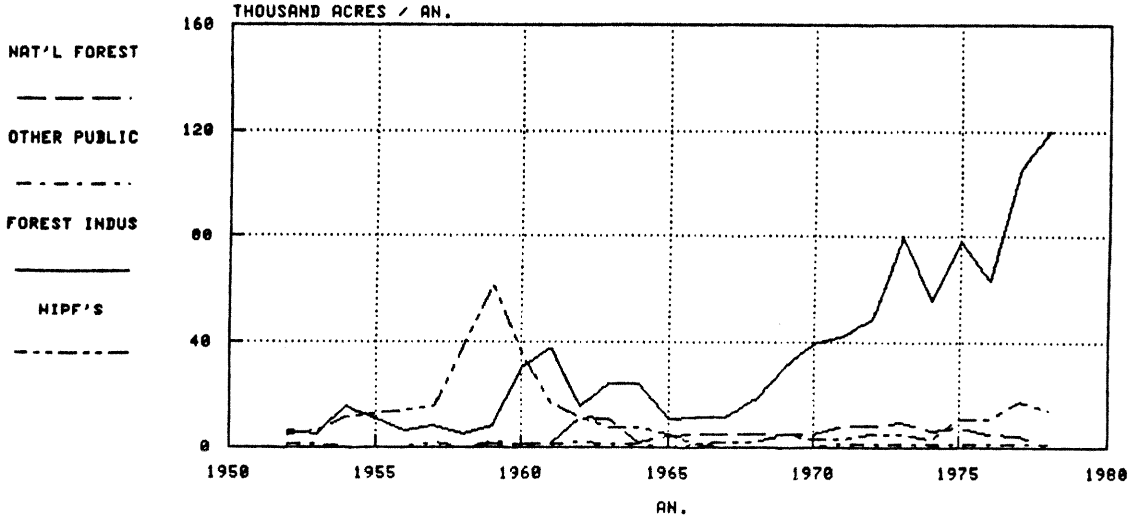
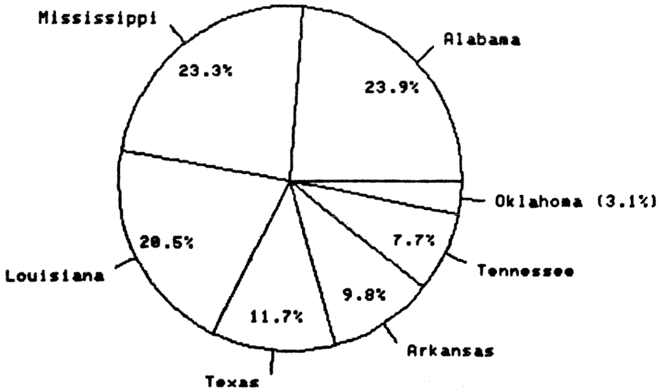


FIGURE 6. PLANTATION ACREAGE

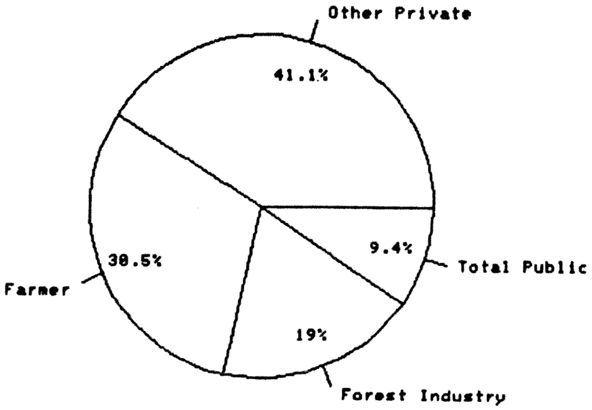
Midsouth States



Based on 10 million acres

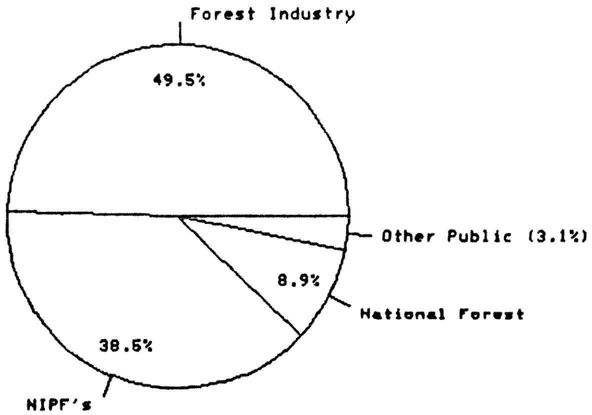
FIGURE 7. OWNERSHIP OF COMMERCIAL FOREST

Midsouth States



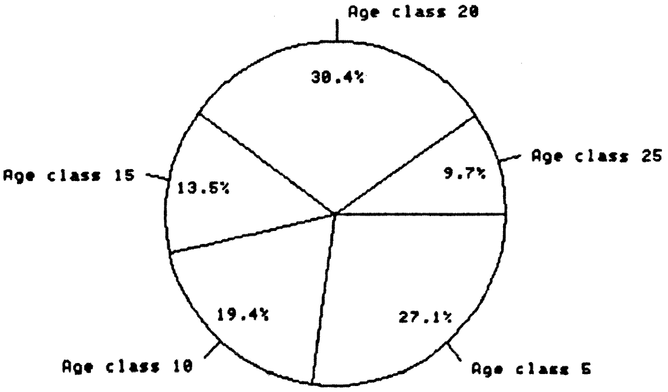
Based on 188 million acres

FIGURE 8. OWNERSHIP OF PLANTATION
Midsouth States (1978)



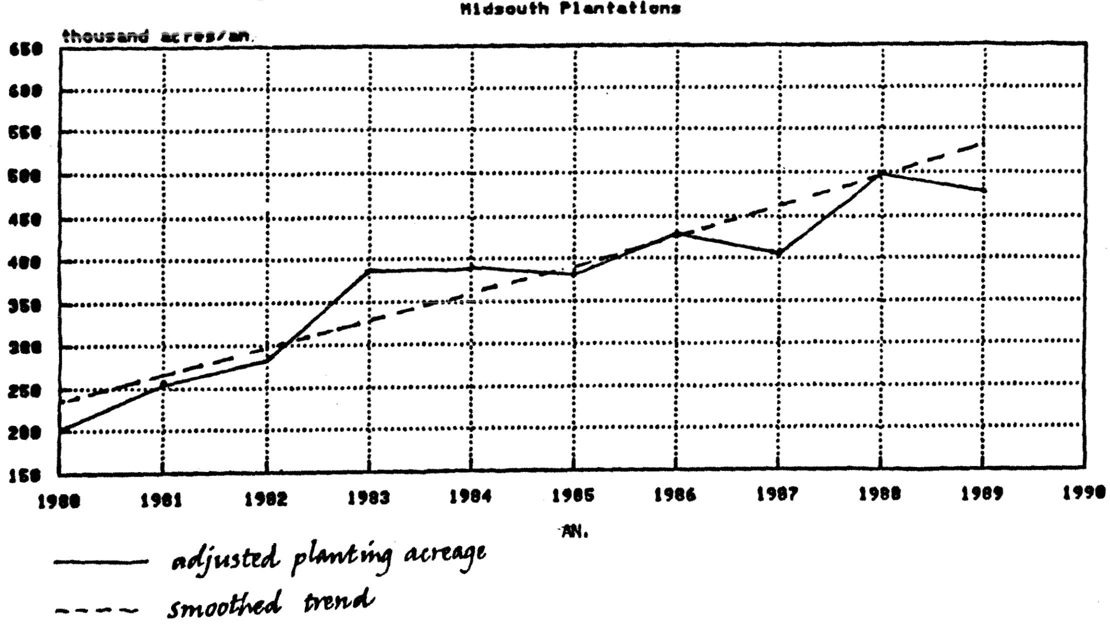
Based on 10 million acres

FIGURE 9. PLANTATION AGE DISTRIBUTION
Midsouth States (1978)



Based on planting records

FIGURE 10. Projected Commercial Thinning Acres



us to estimates for Mississippi and Louisiana. The Mississippi survey was chosen because it is the most recent one completed among the important Gulf Coast states. We are currently updating the inventory of Louisiana so it too seemed a logical choice. It must be noted that yields identified on existing plantations may be poor predictors of future yields on well-managed forest industry lands. Nonetheless, the data we have collected reflects a real work situation in which many plantation acres are not managed at the intensity of some forest industry lands.

Our inventories are based on the careful measurement of not only dbh, but of upper stem diameters on thousands of trees 5.0 inches and larger at breast height. Computation of merchantable volume is on data for an individual tree using routines developed by L. Grosenbaugh. Volumes of individual trees are expanded to a per-acre basis and recorded in cubic feet per acre. Further calculations of cords per acre are based on utilization studies.

Distribution of site classes (Figure 11) might give an idea of the potential number of acres producing better returns than those reported in Tables 1 - 4. Notice that the better sites are producing at least 85 cu. ft./acre. Based on our cubic foot to standard cord conversion factors, this is a little more than 1 cord per acre per year.

Thinning yields of pine only in Mississippi and Louisiana are low compared to those found in the Southeastern region. Two of many possible reasons for this condition are cited. First, much of the data comes from Soil Bank era planting. On average these acres reflect a lower intensity of management--typical of many NIPF acres. Second, in some areas hardwood competition forms a significant portion of the basal area and volume. (The volumes reported are strictly for pine).

Tables 1 - 4 summarize average stocking and volumes in plantations in Mississippi. Our tables represent volumes on medium site lands. Total area refers to the estimate of the acres in a given age class. Yields refer to probable cords per acre produced as a result of thinning an average acre to 60 square feet of basal area and conversion of cubic foot volume to standard cords. Volumes reported are exclusively pine. Table 1 portrays volumes and stocking for the Northern Unite (2) of Mississippi. Plantations are primarily Loblolly on pine type sites. Table 2 shows similar parameters for Central Mississippi (Unit 3). The probable thinning yields are highest for this unit, still they are lower than the projections given for Atlantic South plantations of medium site. Table 3 (Unit 4 Southeast Mississippi) is characterized by lower per acre volumes and basal areas at age 15 for sites which are primarily slash pine type. Totals for the state are not much different than the individual units. The potential yields reported here are for average conditions, but they suggest that the 15 year age class (a class dictated by inventory data collection routines) is still a little young to expect substantial thinning

The young loblolly plantations in Louisiana (ages 1 - 10 and 11 - 20) were compared to expected yields which are predicted in the Forest Service publication Yields of unthinned Loblolly pine plantations on cutover sites in the west Gulf Region (SO-148, Feduccia, et al.). Based on the number of trees surviving, site index and age since planting there was remarkable agreement, on the average, between the predicted yields and totals observed inventory. The numbers of cords of pine available through thinnings generally follows the pattern established in Mississippi data.

We feel that average volumes will be considerably greater when the increases in forest industry managed lands begin to appear in the statistics. In addition if we remember that plantation forestry was much better developed in the Atlantic South during the Soil Bank era it is land's production levels is present in the Mississippi-Louisiana data than in comparable Atlantic data. There is also a good deal of volume in hardwood on the plantations found in Mississippi. If this volume is directly utilized or converted to pine through proper site occupancy and maintenance, it increases the net volumes available from the site significantly. Stands which will reach thinning age during the 80's originated more recently than the ones analyzed and the impact of improved forest management should be realized during the 80's.

To put potential volumes in perspective, consider the pulp production for the seven-state area (Figure 12). There were a total of 25 million standard cords reported in Southern Pulpwood Production, 1977. During the past 20 years roundwood production has increased significantly from 6 million to 12 million standard cords per year. Most of the increase occurred between 1965 and 1970. The most recent increases in overall pulp production have come from better utilization of wood residues. Wood residues, which accounted for 5 - 15 percent of the pulp production during the 1960's, now contribute 35 percent of the total. Further expansions in pulping capacity may be possible through gains in utilization of residues. However, a major opportunity for increased production will be available from thinnings, especially toward the end of the coming decade. Potential thinning volumes in the Midsouth at the end of the period will approach 1.25 million cords even at conservative levels used for predicition in this paper. This represents nearly 15 percent of the current annual softwood roundwood production. If average per acre volumes increase significantly due to the impact of better management expected in the region during the 80's, the figure could be closer to 5 million cords or 50 percent of the total.

In summary, review Figure 10. Regardless of the interval between planting and commercial thinning, be it 15 or 20 years, there is an imminent expansion of the acres suitable for thinning in the Midsouth. This expansion willtake place during a period of anticipated economic uncertainty. This could signal a shift in emphasis onto activities that are economically efficient, which could have a serious impact on the potential production of many acres needing to be thinned during the decade. Finally, I'd like to comment on our current, midcycle update of Louisiana Forest Resources. We have obtained high altitude photographs of the pine regions of Louisiana and are currently in the process of constructing an aerial photo key to the condition of recently planted forest industry lands On the ground examination of chosen sites has been completed. We expect to have preliminary results indicating the condition and extent of young Louisiana plantations early in 1981.

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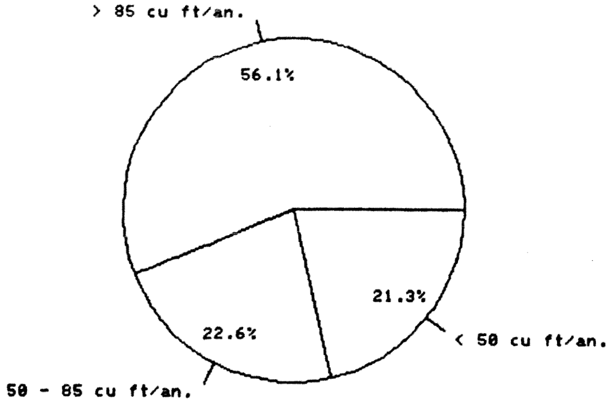
Feduccia, D. P., T. R. Dell, W. F. Mann, T. E. Campbell and B. H. Polmer. 19 . Yields of Unthinned loblolly pine plantations on cutover sites in the West Gulf region. USDA For. Serv. Res. Pap. SO-148, 88 pp.

1977. Forest Statistics of the U. S., 1977. USDA For. Serv. 133 pp.

FIGURE 11. DISTRIBUTION BY SITE CLASS

Plantations in Mississippi



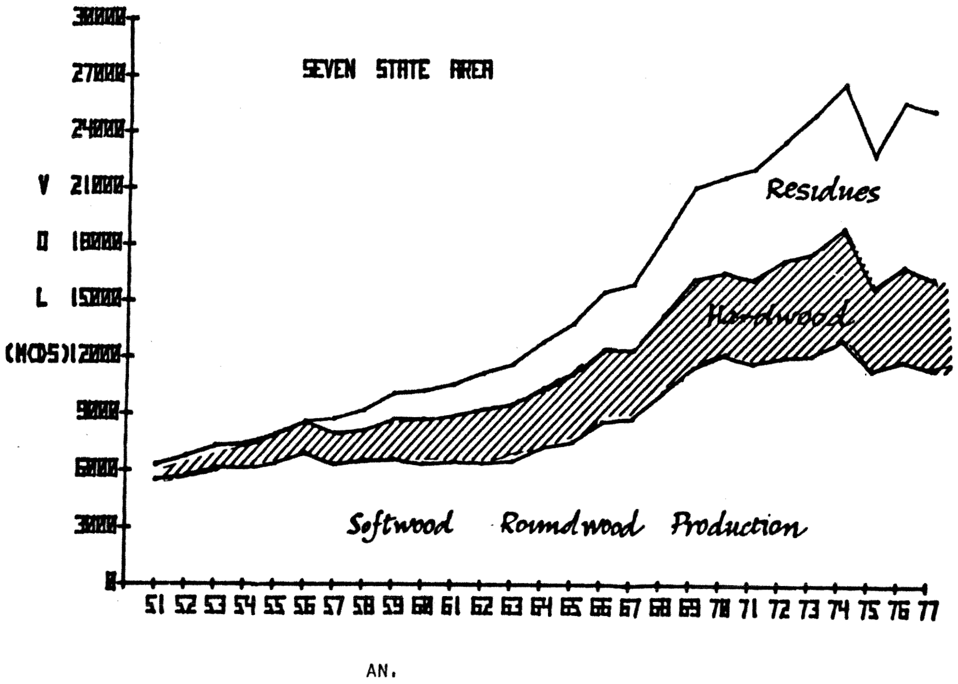


FIGURE 12. Midsouth Pulp Production 1951-1977

Table 1.--Average stocking and volume per acre and acreages
Mississippi Unit 2. (Primarily Loblolly)

Stand age	Trees 5.0 in. dbh and larger			Total Area [1]	
	Basal Area	net volume	standard	thousand	
	(sq. ft.)	(cu. ft.)	cords	acres	
5	30	665	8.9	98	
15	68	685	9.1	242	thinned to 60 ft.^{2} yield = 1 cord
25	85	1146	15.3	132	
35	66	1154	15.4	81	
Mixed	[2]				

[1] Forest survey estimate of total plantation acres in an age class.

[2] Too few plots to make any estimate.

Table 2.--Average stocking and volume per acre and acreages
Mississippi Unit 3. (Primarily Loblolly)

Stand age	Trees 5.0 in. dbh and larger			Total Area	
	Basal Area	net volume	standard	thousand	
	(sq. ft.)	(cu. ft.)	cords	acres	
5	11	100	1.3	179	
15	78	1060	14.2	46	thinned to 60 ft.^{2} yield = 3.2 cords
25	105	1920	25.6	35	
35	60	1100	14.7	29	
Mixed	60	1112	14.8	17	

Table 3.--Average stocking and volume per acre and acreages Mississippi Unit 4. (Primarily slash)

Stand age	Trees 5.0 in.	dbh and larger		Total Area	
	Basal Area	net volume	standard	thousand	
	(sq. ft.)	(cu. ft.)	cords	acres	
5	9	60	.8	317	
15	55	615	8.2	238	less than 60 ft.^{2} no yield
25	80	1065	14.2	68	
35	45	1425	25.0	11 [2]	
Mixed	26	265	3.5	23 [2]	

[2] Very rough estimates.

Table 4.-- Average stocking and volume per acre and acreages State totals for Mississippi (includes unit 1 & 5)

Stand age	Trees 5.0 in.	dbh and larger		Total Area	
	Basal area	net volume	standard	thousand	
	(sq. ft.)	(cu. ft.)	cords	acres	
5	13	170	2.2	622	
15	66	730	9.7	547	thinned to 60 ft.^{2} yield = 0.8 cord
25	85	1230	16.4	236	
35	68	1300	17.3	126	
Mixed	50	670	8.9	52	

SYCAMORE PLANTATION GROWTH: 10-YEAR RESULTS OF SPACING TRIALS[1/]

Bryce E. Schlaegel[2/]

Abstract.--Results of a 10-year spacing trial for sycamores on a good site in the Mississippi Delta are presented. Total cubic-foot production is correlated to initial number of stems, with the 5x10- and 10x10-foot spacing having twice the volume and weight of the widest spacing of 20x20 feet. Projected ages of peak MAI for the 5x10-, 10x10-, 10x20-, and 20x20-foot spacings are 12, 18, 22, and 30 years, respectively. The 10x10 spacing appears to give the most options for production of either pulpwood or sawlogs.

The American sycamore (*Platanus occidentalis* L.) grows relatively fast throughout its life. Sycamore appears most frequently and attains its largest size on alluvial soils. Only cottonwood (*Populus deltoides* Bartr. ex Marsh.), and in some cases, black willow (*Salix nigra* Marsh.) grow faster there (Merz 1958). Because of its rapid growth and relative freedom from serious insect and disease pests, sycamore is widely planted throughout the South. But before establishing a forest plantation, an initial spacing must be determined.

Early sycamore growth is influenced by initial seedling density. Belanger and Pepper (1978) show that total height is decreased by stocking that is either extremely high or low. Total height was greatest at intermediate stocking levels of 1,000 to 5,000 trees per hectare (400 to 2,000 trees per acre). Moderate competition among trees was necessary to obtain maximum height growth.

Close initial spacing offers high yields in early years. Stem yields of 4-year-old seedlings ranged from 14.5 oven-dry tons per acre at a 1x4-foot spacing to 5.9 tons at a 4x6 spacing (Saucier et al. 1972).

Wide spacing distributes growth on fewer stems. The result is larger trees, but the age of maximum mean annual increment is increased. At 11 years of age, mean annual increment was still increasing for Georgia Piedmont sycamore planted at an 8x8-foot spacing (Belanger and Saucier 1975).

This paper presents 10-year results of a sycamore spacing trial with spacings of 5x10, 10x10, 10x20, and 20x20 feet. The spacings are compared for survival, wood density, and present height, basal area, volume, and weight. The age at which stand cubic-foot mean annual increment (MAI) peaks is projected for each spacing.

METHODS

Installation and Measurement

The study area is located in the Mississippi River batture at Huntington Point near Greenville, Miss. The soil is Commerce silt loam, a good sycamore site averaging 108 feet in site index for natural sycamore stands.

A randomized complete block design of four blocks and four spacings was planted in the spring of 1970 with 1/0 seedlings. The spacings and respective numbers of trees per acre were 5x10 feet (871), 10x10 (436), 10x20 (218), and 20x20 (109). Competition from herbaceous and woody vegetation was reduced by mechanical disking several times a year for the first 2 years.

Each of the 16 plots consists of a 13x13-row sample plot, the interior 7x7-measurement rows and 3 buffer rows. Annual dbh measures are taken on 49 measurement trees; total heights are measured on the center two rows, or about 15 trees.

[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

[2/] Mensurationist, Southern Hardwoods Laboratory, which is maintained at Stoneville, Mississippi, by the Southern Forest Experiment Station, Forest Service--USDA, in cooperation with the Mississippi Agricultural and Forestry Experiment Station and the Southern Hardwood Forest Research Group.

Deriving Volume and Weight Equations

Volume and weight equations exist for plantation-grown sycamore in the Georgia Piedmont (Belanger 1973). However, these equations were developed from trees of a single 8x8-foot spacing using form factor equations. Using Belanger's equations in this spacing study to calculate tree volumes and weights overestimates tree volumes in the widely-spaced plots and underestimates tree volumes in the narrowly-spaced plots. The net result is to mask the differences in tree form that exist between spacings. To overcome this problem, separate volume and weight equations were developed for each spacing.

During the summer of 1979, five trees per plot were randomly selected and felled from the middle border row of each plot, for a total of 20 sample trees per spacing. Stump heights were about 0.2 feet. Sample disks were removed from the base of the stem and at intervals of H/20, each disk coming from the same relative position on the stem; an additional disk was removed at dbh.

A stem analysis was done on each disk by measuring annual rings on the average disk radius. Bark thickness on the average radius was measured to the nearest 0.04 inch. Tree volume for each annual sheath was calculated by summing bolt volumes calculated by Newton's formula (Husch et al. 1972).

Outside bark radii for prior years were estimated by regressing current radius outside bark (ROB) separately for each spacing as a linear function of radius inside bark (RIB) so that ROB = a + b (RIB). A random sample of three disks from each tree were used to represent all ages and sizes of disks. The following tabulation gives estimates of a and b for the preceding model for predicting outside bark radius in inches from a known inside bark radius:

Spacing	a	b	R^2	$S_{y.x}$
5x10	0.027	1.018	0.99966	0.012
10x10	0.026	1.021	0.99973	0.001
10x20	0.032	1.021	0.99937	0.001
20x20	0.026	1.030	0.99964	0.001

After the stem analysis, the odd-numbered disks were analyzed for moisture content and specific gravity. All odd-numbered disks for each tree were consolidated into a single sample for that tree. All bark was removed, the disks were collectively weighed green, volumes obtained by water immersion, and then ovendried in a forced fan oven at 105°C for 48 hours. Moisture content and specific gravity were obtained for each tree. Since no way was available for estimating specific gravity for individual ages, the assumption was made that tree wood density of each spacing has remained constant over time and estimated stem dry weight at the ith age (DW_i) as the product of its volume from the stem analysis (V_i) times its present average specific gravity (SG) times 62.43;

i.e. $DW_i = V_i \times SG \times 62.43$.

Volumes and weights obtained from stem analysis were treated as independent observations and fit by nonlinear least squares techniques to the model

$$W_i = b_0 D_i^{b_1} H_i^{b_2} \qquad (1)$$

where

D_i = the dbh of the ith tree.

H_i = total tree height of the ith tree.

W_i = stem cubic-foot volume or dry weight in pounds of the ith tree.

The parameter estimates and accuracy statistics for model 1 are presented in table 1. All data fit the model with a fit index of at least 0.975.

Deriving the Height Equations

The volume equations require both diameter and total height measures. However, only dbh was measured on all trees each year. Therefore, total height was estimated for each tree in order to calculate tree volume and weight.

Plotting total tree height over dbh for each spacing for all ages indicated that initial spacing greatly influences average total tree height. Low densities had significantly less height growth for the first 5 years. This agrees with the results of Belanger and Pepper (1978). Therefore, a separate height prediction model was fit for each spacing as a function of tree dbh and age:

$$H_i = b_0 + b_1 X_i + b_2 X_i^2 \qquad (2)$$

where

$X_i = A_i Ln(D_i)$; the natural logarithm of the dbh of the ith tree times its age

H_i = total height in feet, and

the b_i are coefficients estimated from the data (table 2).

Table 1.--Parameter[1] estimates and accuracy statistics for estimating sycamore bole wood volume and weight[2]

Spacing	n	b_0	b_1	b_2	Fit index[3]	Standard error of estimate	Coefficient of variation[4]
Feet						*Feet*	*Percent*
			Cubic-foot volume				
5x10	198	0.00219	1.82368	1.10810	0.979	0.17	12.0
10x10	195	0.00270	1.88955	1.02193	0.993	0.15	6.9
10x20	189	0.00210	1.88815	1.08123	0.990	0.20	8.2
20x20	195	0.00252	1.66346	1.14185	0.979	0.46	13.2
			Dry weight - pounds				
5x10	198	0.05842	1.97868	1.04351	0.975	4.98	13.2
10x10	195	0.06783	1.87341	1.04794	0.991	4.53	7.7
10x20	189	0.05508	1.94481	1.06576	0.986	6.82	10.1
20x20	195	0.08832	1.87976	0.96516	0.979	13.07	13.3

[1] $\hat{Y} = b_0 D^{b_1} H^{b_2}$

[2] Volumes and weights of trees from a 0.2 foot stump to the tree tip.

[3] Fit index = $1 - [\Sigma(Y-\hat{Y})^2/\Sigma(Y-\bar{Y})^2]$.

[4] Coefficient of variation = 100 (standard error of estimate/$\bar{Y}$).

Table 2.--Coefficients through age 10 for estimating sycamore total tree height (feet) for a given spacing[1]

Spacing	Coefficient b_0	b_1	b_2	R^2	Standard error of estimate	Coefficient of variation[2]
Feet					*Feet*	*Percent*
5x10	15.33	2.93319	-0.04012	0.857	3.56	8.6
10x10	12.89	2.81507	-0.02270	0.950	2.68	6.1
10x20	14.28	2.06441	-0.00218	0.900	3.27	7.8
20x20	13.80	1.54306	0.01468	0.932	3.24	8.0

[1] $H = b_0 + b_1 [A\mathrm{Ln}(D)] + b_2 [A\mathrm{Ln}(D)]^2$; A = tree age, D = dbh.

[2] Coefficient of variation = 100 (standard error of estimate/$\bar{Y}$).

RESULTS

After 10 years the 5x10-foot spacing averages 77% survival while the other three spacings average 93% (table 3). This high mortality in the narrow spacing is due to competition, since at the end of two growing seasons no differences in survival existed due to spacing. Average stand height of all trees is about 5 feet lower for the 5x10 spacing, a reversal from age 5 when the two narrow spacings averaged 4 feet taller than the two widest spacings.

Average dbh is related directly to spacing; tree dbh increases with an increase in spacing.

Total basal areas per acre range from 49 sq. ft. for the 20x20-foot spacing to 84 sq. ft. for the 5x10-foot spacing. Similarly, bole wood volumes range from 1,057 to 2,011 cu. ft. per acre and bole dry weights range from 29,660 to 53,509 pounds per acre. The 10x10 spacing has the same volume as the 5x10 and a higher dry weight per acre due to higher wood specific gravity. The 20x20 spacing has only about one-half the volume as the 5x10. But 94% of the volume is on trees 8 inches dbh and larger, while the two narrow spacings average 2% and 15% on large diameter trees (table 4).

Specific gravity is directly correlated with growth rate, with the faster-growing trees exhibiting the highest specific gravity at 0.452 while specific gravity for the slower-growing trees averages 0.422. These figures are considerably lower than either the 0.54 (Panshin et al. 1964) or 0.49 (U.S. Forest Products Laboratory 1974), which have been listed for the species. But similar results due to spacing were noted by Saucier et al. (1972).

Although mean annual increment (MAI) has not yet peaked for any of the spacings in this study (fig. 1), it can still be determined for each of the spacings by separately considering the components of stand volume.

Volume (V) of an even-aged stand can be determined if three factors are known: 1 - its basal area (B), 2 - its average total height (H), and 3 - the average form factor (F). Thus,

$$V = FBH \tag{3}$$

and cubic-foot volume mean annual increment is

$$MAI = V/A = (FBH)/A \tag{4}$$

or,

$$MAI = (FB)\ H/A, \tag{5}$$

where A is the stand age in years and V, F, B, and H are previously defined.

Equations were derived for each spacing to estimate B, F, and H/A. Substituting these into (5) and solving for each year show that MAI will peak for the 5x10, 10x10, 10x20, and 20x20-foot spacing at ages 12, 18, 22, and 30, respectively,

Table 3.--Average 10-year results for a sycamore spacing trial

Item	Spacing 5x10	10x10	10x20	20x20
Survival - *percent*	77	90	96	94
Dbh - *inches*	4.8	6.1	7.4	9.4
Total height - *predicted feet*	50	55	54	55
Basal area per acre - *sq. ft.*	84	80	61	49
Bole wood volume per acre - *cu. ft.*	2,011	2,003	1,435	1,057
Bole dry weight per acre - *pounds*	53,509	54,256	39,739	29,660
Wood specific gravity	0.422	0.429	0.439	0.452
Bole form factor	0.478	0.454	0.435	0.391

Table 4.--Distribution by dbh class of bole wood cubic-foot volume of a 10-year-old sycamore spacing trial

Dbh class	Spacing 5x10	10x10	10x20	20x20
		Volume - *cubic feet*		
1	1			
2	8			
3	101	17	1	
4	525	70	10	1
5	690	278	58	3
6	470	690	153	26
7	175	647	343	38
8	41	252	519	122
9		49	322	270
10			29	251
11				217
12				129
Total	2011	2003	1435	1057
% $\geq$8" dbh	2	15	61	94

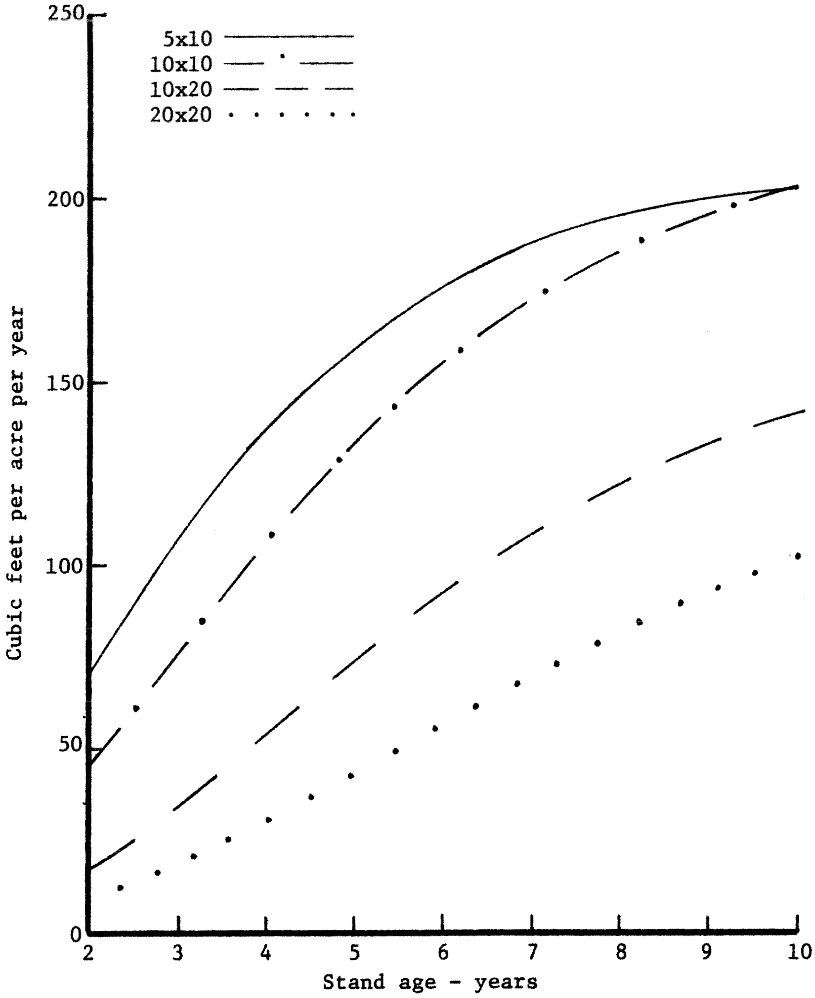


Figure 1.--Cubic-foot volume mean annual increment for a sycamore spacing trial.

with peak MAI's of 204, 219, 167, and 144 cu. ft. per acre per year.

DISCUSSION

Results after 10 years show that tree size and stand volume and weight are directly affected by initial spacing. The closer spacings result in relatively higher stand volume at age 10 than wide spacings, but average tree size is smaller. The 20x20 spacing has only half the volume of the close spacings, but it is placed on small sawlog-sized trees.

Initial spacing will depend upon the product objectives. If fiber is the sole objective, then a close initial spacing with a complete clearcut and replanting when MAI peaks should be the management strategy.

A wide initial spacing will produce small sawlogs by age 10. However, the site is underutilized until the crowns close. And sawlog quality is low due to lack of natural pruning until after crown closure.

The most favorable spacing in this study appears to be the 10x10. It has volume or weight equal to or better than the 5x10 with half the initial density. It can be clearcut for fiber at age 18 when MAI peaks. Or it can be row-thinned after natural pruning to the height of one sawlog, at about age 9 or 10. This would give an early investment return and leave clean-boled trees for future sawlog production.

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TAPER FUNCTIONS FOR UNTHINNED LONGLEAF PINE PLANTATIONS ON CUTOVER WEST GULF SITES[1]

V. C. Baldwin, Jr. and B. H. Polmer[2]

Abstract.--Longleaf pine stem taper was modeled using unthinned plantation data from 10 Texas and Louisiana stands. Sample trees were 10 to 44 years old with dbh from 1 to 21 inches. Inside- and outside-bark taper functions are presented and discussed.

INTRODUCTION

Standing tree volume estimation by appropriate integration of a taper curve is one of the most accurate and flexible techniques available. Taper functions also facilitate estimation of other parameters such as stem surface area. The method is particularly valuable when multiproduct yields are desired.

Taper functions for loblolly and slash pine are used in some of the most recent yield prediction systems (Bennett et al. 1978; Dell et al. 1979; Feduccia et al. 1979) and a number of taper models for these species have been published (e.g., Liu and Keister 1978; Max and Burkhart 1976; Matney and Sullivan 1980). To date, however, a taper model for planted longleaf pine has not been published although one has been fitted for natural longleaf stems and publication is pending.[3] As part of a study to develop green- and dry-weight equations for unthinned longleaf pine plantations, inside- and outside-bark taper functions were fitted and are described in this paper. The models were developed by Bennett et al. (1978) and later applied by Dell (1979) and Dell et al. (1979). Equation development and rationale for the models are covered in those publications.

DATA

Sample trees came from long term growth and yield study plots established in 10 unthinned longleaf pine plantations located on cutover sites in central Louisiana and east Texas. Plantation ages ranged from 10 to 44 years and site index (base age 25) ranged from 41 to 76.

Trees were selected to represent a wide dbh range in three varying height classes per diameter class and three crown ratio classes per height class. Crown ratio (in percent) is defined as 100 (length of full live crown)/(total height of the tree). Distribution of the sample trees by dbh, crown ratio, height and age is presented in table 1. Sample trees were free from forking, excessive sweep, and any effects of disease or mechanical damage which would tend to make them atypical. Measurements were taken during the summer of 1979.

Total height, dbh, and height to the base of the live crown were measured for each tree before felling. After felling all measurements were repeated for verification. Following removal of all branches from the bole, diameter inside- and outside-bark and height above groundline were measured at dbh and at each 1-inch taper step from the stump to the tip. For both inside- and outside-bark measurements, the average of two caliper readings to the nearest 0.1 inch were recorded at each measurement point.

THE MODELS

Since the basic model assumptions, derivations and applications are given in detail in Bennett et al. (1978) and Dell et al. (1979), only the models used and the information needed for application with planted longleaf pine are presented.

Define:

h = height above ground (feet),

h_s = average stump height (feet),

D = diameter outside bark at breast height, (inches),

H = total tree height (feet),

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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[3] R. M. Farrar, personal communication, 1980.

$CR(i)$ = the ith crown ratio class where

$i = 1$ when, $CR < 36$ percent,

$i = 2$ when, 36 percent $\le CR \le$ 50 percent,

$i = 3$ when, $CR > 50$ percent,

$\hat{d}_{ib}(h)$ = a general expression for the predicted diameter inside bark (inches) as a function of height (h) above the ground,

$\hat{d}_{ob}(h)$ = as immediately above for diameter outside bark (inches).

Different expressions for $d_{ib}(h)$ or $d_{ob}(h)$ are used for $h \le 4.5$ feet and $h \ge 4.5$ feet but the taper models are constrained so the two segments come together at breast height.

The models are:

I. Outside-bark taper model,

$$\hat{d}_{ob}(h) = \begin{cases} D(h/4.5)^{\eta_{ob}}, & h_s \le h \le 4.5 \qquad (1a) \\ D(H-h)/(H-4.5) & \\ + \beta_{1_{ob}} (H-h)(h-4.5)/H^2 & \\ + \beta_{2_{ob}} D(H-h)(h-4.5)/H^2 & \\ + \beta_{3_{ob}} D^2 (H-h)(h-4.5)/H^2 & \\ + \beta_{4_{ob}} (H-h)(h-4.5)(2H-h-4.5)/H^3, & 4.5 \le h \le H \qquad (1b) \end{cases}$$

II. Inside-bark taper model,

$$\hat{d}_{ib}(h) = \begin{cases} (\gamma_1 + \gamma_2 D)(h/4.5)^{\eta_{ib}} & h_s \le h \le 4.5 \qquad (2a) \\ (\gamma_1 + \gamma_2 D(H-h)/(H-4.5) & \\ + \beta_{1_{ib}} (H-h)(h-4.5)/H^2 & \\ + \beta_{2_{ib}} \cdot (\gamma_1 + \gamma_2 D)(H-h)(h-4.5)/H^2 & \\ + \beta_{3_{ib}} (\gamma_1 + \gamma_2 D)^2 (H-h)(h-4.5)/H^2 & \\ + \beta_{4_{ib}} (H-h)(h-4.5)(2H-h-4.5)/H3, & 4.5 \le h \le H \qquad (2b) \end{cases}$$

These inside- and outside-bark models were fitted to our data using least squares estimation procedures. Separate sets of coefficients were independently estimated for each of the three broad crown ratio classes defined. The model coefficients and associated fit statistics are presented in table 2.

Taper functions are commonly used to obtain stem volume of standing trees. Cubic-foot volume inside- or outside-bark for a stem section between heights h_l and h_u ($h_l < h_u$) is estimated by revolving the appropriate taper curve, $d_{(\ )}(h)$ between h_l and h_u for a given CR(i) around the h-axis. The mathematical expression for the volume of this solid of revolution is

$$\mathrm{Vol}_{(\ )} = \int_{h_l}^{h_u} \pi [d_{(\ )}(h)]^2/4(144)\ dh. \qquad (3)$$

The specific inside- and outside-bark volume predicting equations resulting from evaluation of the above integral are lengthy and therefore are not presented here. The prediction equations are given in Bennett et al. (1978) and utilization of their equations with our coefficients is straightforward. Also, the USLYCOWG computer program (Dell et al. 1979; Feduccia et al. 1979) contains the complete volume predicting system in subroutines which only need slight alteration and input of our coefficients for use with longleaf pine.[4]

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[4] The USLYCOWG FORTRAN computer program is available from the Southern Forest Experiment Station, Statistical Methods for Research and Application, T-10210, 701 Loyola Avenue, New Orleans, LA 70113.

DISCUSSION AND CONCLUSIONS

Data were not available for direct validation of our models. However, a number of internal and external checks were made.

All the taper equations were evaluated by summarizing trends in deviations between predicted and observed values for the observations upon which they were based, and graphs were developed to ensure that predictions were reasonable. No unusual or misleading predictions were discovered. The statistics given in table 2 do reflect the generally good fit obtained in the modeling process.

A number of taper-graph sets, similar to those in figure 1, were produced for different height, diameter and crown ratio combinations so we could visualize model performance over a range of conditions. The graphs clearly illustrate, for example, the thicker bark and greater taper in the high, as compared to the low, crown ratio trees.

The volume equations derived from our taper models were also used to generate total and merchantable cubic-foot volumes, within each crown ratio class, for a number of total height and dbh combinations (table 3). These volumes were compared with volumes predicted in the same manner by other longleaf pine volume equations. Models used were (1) Schmitt and Bower (1970), (2) U. S. Forest Service (1929) and (3) Farrar.[5]

The Schmitt and Bower equations were the only plantation pine volume predictors available, but they were developed to estimate small tree (< 8 inches dbh inside bark) cubic-foot volumes in young plantations. The FS publication offers volumes in tabular form only for fully stocked natural stands of longleaf pine throughout the South. Farrar's data came from naturally established thinned and unthinned stands in the east Gulf Region. Comparisons were made subject to data restrictions imposed both by our equations and the other equations. This requirement was relaxed somewhat for the Schmitt and Bower comparisons because of the differences in tree heights between the two data sets. Table 3 gives the dbh-height combinations used for these comparisons. The volumes predicted from the other equations were considered to be those "observed" in the statistics we generated.

For each situation considered, the correlation of "observed" and predicted total inside-bark volumes was computed. Also computed was the mean percent deviation, which is the average of the 100 (predicted-"observed")/"observed" values. In each case the correlation coefficient was positive and at least r = .99. These statistics offered assurances that the equations were at least predicting in a general manner like unto the others. However, the mean percent deviations revealed the most interesting points and confirmed some expected results:

	Reference Model	Mean Percent Deviation		
		CR < 36	36 ≤ CR ≤ 50	CR > 50
1	Schmitt and Bower	4.46	2.26	-17.29
2	US Forest Service	-0.78	-1.41	- 8.01
3	Farrar	-0.94	-1.65	- 8.57

Overall, these statistics indicate the models' predictions were biologically as well as mathematically meaningful. For example, the noticeably low mean percent deviations in the high crown ratio class in each case reflect the magnitude of total volume overprediction for these trees. This result might be expected when any volume equations are used which do not account for tree taper differences. The results confirm that in most cases a higher crown ratio in longleaf pine trees implies comparatively lower total stem volumes. The higher crown ratio generally results from a more open stand structure during tree development and thus more taper in the upper stems of the trees.

Also, the last six slightly negative mean percent deviations suggest our model may underpredict volumes if used in natural longleaf pine stands. This finding, although not conclusive, is reasonable assuming total tree volumes in longleaf pine plantations will be less, on average, than volumes of natural longleaf trees of the same dbh and height because of the greater upper stem taper expected in plantation trees which are grown under relatively low density, regularly spaced conditions.

There are exceptions, of course. Dell (1979) pointed out that for certain situations volumes are greater with higher crown ratios in the low- to mid-portions of plantation loblolly and slash, and natural longleaf pine stems. In our data this phenomenon was also evident in trees less than 8 inches dbh in the stem portion from about 5 to 18 feet above groundline.

A comparison with the Schmitt and Bower (1970) young plantation equation (model 1) also indicate the importance of considering age, initial planting spacing and present stand structure before selecting a particular volume equation. Our functions overpredicted volumes using the CR(1) and CR(2) models, but noticeably underpredicted with the CR(3) model. The trees used to build Model 1 had a wide initial spacing (10' x 10') and most were expected to have crown ratios exceeding 50 percent. However, the CR(3) model apparently did a poor job of predicting the volumes of those trees relative to, say, the CR(2) model. Although the crown ratio distribution of the Model 1 plantation trees isn't known, it is known that they were younger and shorter, on average, than those used in our model (age 7 years and height range of 5-33 feet). This compares with a mean age of 26 years, and height range of 12-70 feet, respectively,

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[5] Farrar, R. M. Cubic-foot volume, surface area, and merchantable height functions for longleaf pine trees. Manuscript in preparation.

for trees in the dbh range indicated in table 3. However, most of our low dbh sample trees were older, suppressed or intermediate trees and not indicative of the typical trees found in young, vigorously growing plantations. Also, the size of our sample in these smaller diameter classes was only one-fourth the size of theirs. And there is always the problem of greater estimate variability when using predictors that are close to the endpoints of the model's database. Hence, in spite of the advantages of our taper models, the Schmitt and Bower (1970) equation is a better volume model to use in young, widely spaced longleaf pine plantations.

When using these taper models for any desired application, the crown ratio classes are broad enough so standing trees can easily be assigned a crown ratio class visually, if height to the base of the live crown was not measured, and the appropriate equation utilized. Proper crown ratio class assignments can also be made fairly accurately based on plantation age and density. Lacking any of this information, the model for the middle crown ratio class should be used.

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Table 1.--Distribution of the sample trees by diameter, live crown ratio, height and age, and the recommended maximum range of taper curve application (inside heavy lines)

D.B.H.	Age		Total Height		Number	Distribution by height class*			Distribution by crown ratio class†		
class	Mean	Range	Mean	Range	of trees	Short	Medium	Tall	CR < 36	36 ≤ CR ≤ 50	CR > 50
1	26	25-27	12	12-14	3	0	1	2	1	2	0
2	23	10-40	19	15-23	8	3	2	3	2	3	3
3	27	23-40	34	20-46	8	2	2	4	2	2	4
4	24	22-25	44	33-54	6	1	3	2	2	2	2
5	24	22-27	47	36-58	6	2	3	1	2	1	3
6	28	22-40	51	33-66	6	2	3	1	3	0	3
7	26	22-40	60	44-70	7	1	4	2	1	3	3
8	30	22-40	70	58-79	6	0	3	3	2	3	1
9	28	22-40	69	57-83	8	3	1	4	1	6	1
10	33	23-40	77	73-85	8	1	2	5	3	5	0
11	35	22-44	76	62-87	8	1	4	3	2	3	3
12	30	22-40	79	65-86	5	1	1	3	0	2	3
13	33	23-40	79	71-87	6	1	2	3	1	3	2
14	39	23-44	81	74-90	6	0	2	4	0	3	3
15	37	23-44	82	76-85	5	0	1	4	0	4	1
16	42	40-44	77	69-88	5	2	1	2	0	3	2
17	44	40-44	78	70-90	5	1	3	1	0	1	4
18	43	40-44	83	79-86	3	0	1	2	0	0	3
19	43	40-44	75	72-78	3	1	2	0	0	0	3
20	--	--	--	--	-	-	-	-	-	-	-
21	44	44	83	83	1	0	0	1	0	0	1
Totals	33	10-44	62	12-90	113	22	41	50	22	46	45

*Short, medium and large tree height classes increase relative to increases in diameter.
†CR = Live crown ratio in percent.

Table 2.--Equation coefficients and statistics of fit for the taper models

	CR* ≤ 36			36 ≤ CR ≤ 50			CR ≥ 50		
Coefficient	Estimate	R^2†	SEE#	Estimate	R^2	SEE	Estimate	R^2	SEE
$\hat{\beta}_{1_{ob}}$	17.005064	.9345	.3021	12.714490	.9924	.4049	7.064397	.8724	.4937
$\hat{\beta}_{2_{ob}}$	1.215630			2.024789			1.082622		
$\hat{\beta}_{3_{ob}}$	- 0.008585			- 0.072514			-0.029041		
$\hat{\beta}_{4_{ob}}$	-14.123470			-12.484350			-5.707780		
$\hat{\eta}_{ob}$	- 0.086751	.8552	.0772	- 0.091896	.9320	.0468	-0.102462	.9327	.0510
$\hat{\beta}_{1_{ib}}$	14.091790	.9443	.2779	6.309718	.9223	.4083	-1.018126	.8814	.5022
$\hat{\beta}_{2_{ib}}$	1.187514			2.217892			1.178190		
$\hat{\beta}_{3_{ib}}$	- 0.003004			- 0.088708			-0.032456		
$\hat{\beta}_{4_{ib}}$	-11.655900			- 7.667510			0.285117		
$\hat{\eta}_{ib}$	- 0.084656	.7552	.1043	- 0.082441	.8986	.0522	-0.093852	.8103	.0838
$\hat{\gamma}_1$	- 0.393140	.9938	.2375	- 0.302410	.9967	.2434	-0.595800	.9938	.4270
$\hat{\gamma}_2$	0.937690			0.917050			0.915140		

*CR = live crown ratio in percent

†R^2 = coefficient of determination

#SEE = standard error of the estimate

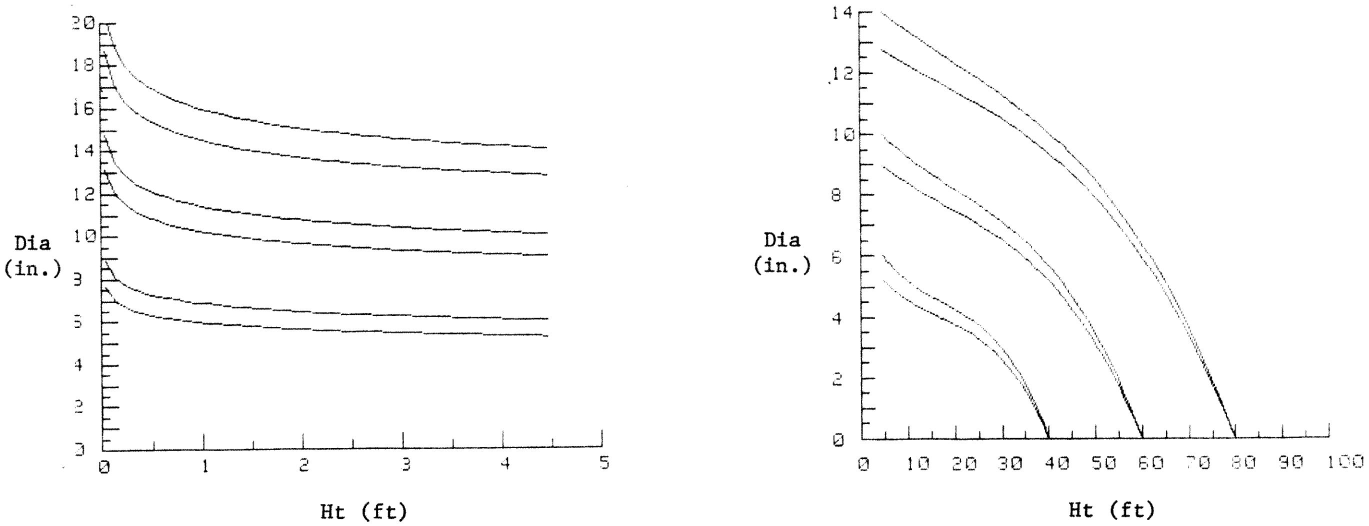
Table 3.--Diameter at breast height-total height combinations used in taper function versus alternative functions volume prediction comparisons*

Diameter	Total height (feet)										
(in.)	10	15	20	25	30	40	50	60	70	80	90
2	S	S	S								
3		S	S	S							
4			S	S	S,F,U	F,U	F,U				
5				S	S						
6				S	S,F,U	F,U	F,U	F,U			
7					S						
8						F	F,U	F,U	F,U	F,U	
10							F	F,U	F,U	F,U	U
12								F	F,U	F,U	F,U
14								F	F,U	F,U	F,U
16									F,U	F,U	F,U
18									F	F,U	F,U

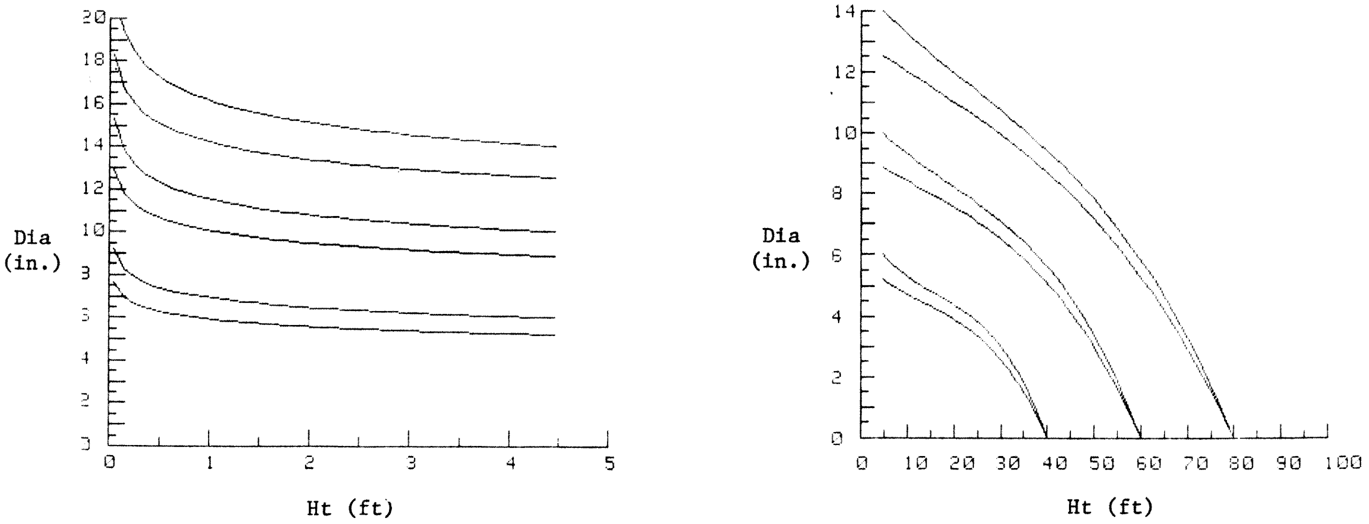
*S, F or U indicates that a Schmitt and Bower (1970), Farrar, or USDA Forest Service (1929) equation, respectively, predicted total volume, for the given height-diameter combination, was compared with a taper equation volume predicted for the same height and diameter.

Figure 1.--Examples of inside- and outside-bark taper for three trees of typical dimensions for three live crown ratio classes

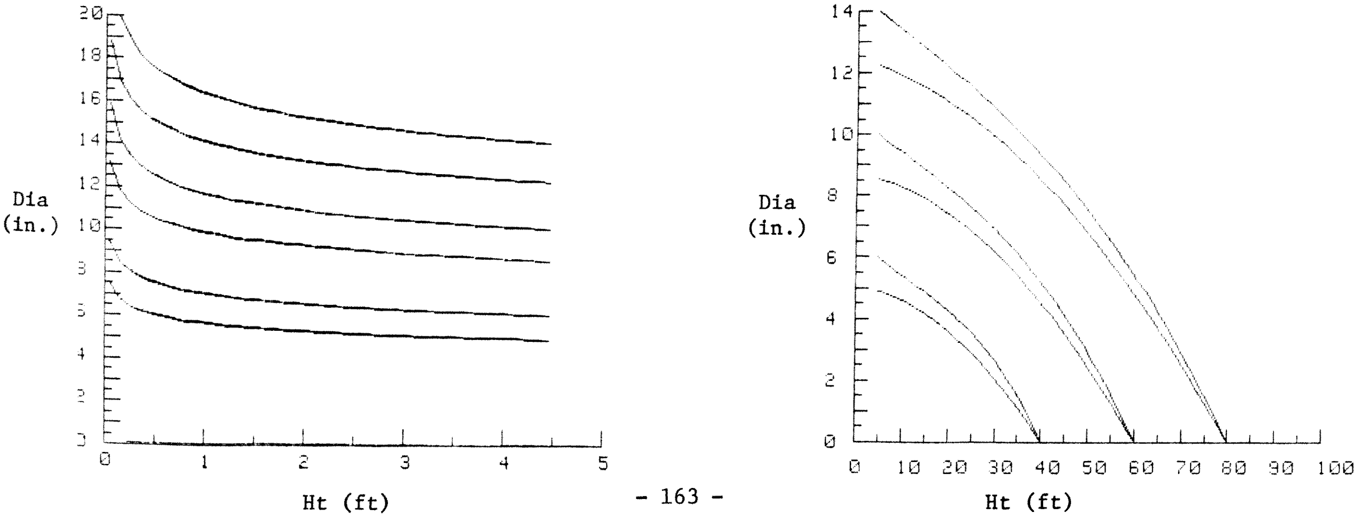
CR < 36



36 ≤ CR ≤ 50



CR > 50



EVALUATING A DIAMETER-LIMIT CUT IN SOUTHERN APPALACHIAN HARDWOODS THROUGH STEM ANALYSIS[1]

Donald E. Beck[2]

Abstract.--Stem analysis of all trees on sample plots was used to evaluate a diameter-limit cut made 27 years earlier. Most of the present stand developed from the 71 saplings and poles per acre with 26 square feet of basal area that remained after harvest. These trees ranged from 35 to 137 years old and were in suppressed and intermediate crown positions prior to release. Growth response was surprisingly good.

THE SITUATION

Numerous broad-scale studies of silvicultural systems and harvest cutting methods were installed on experimental forests 25 or more years ago. Many such areas are intact and can furnish much information on long-term stand development. In one case on Bent Creek Experimental Forest near Asheville, North Carolina, records showed that a 6.5-acre stand had been cut to a diameter limit 27 years previously in 1952-53. Cruise records by 2-inch diameter class for trees 5 inches and larger show that before the cut the stand contained 119 trees with 81 square feet of basal area and 7,834 board feet of sawtimber per acre (tables 1 and 2). By basal area, the stand was 49 percent oak (Quercus spp.), 34 percent yellow-poplar (Liriodendron tulipifera), 9 percent red maple (Acer rubrum), and 8 percent miscellaneous species. The stand is situated on the lower one-third of an east-facing slope. Site quality is excellent with site index for yellow-poplar of 100 feet or more at 50 years.

Table 1.--Number of trees per acre, by diameter class [1]

Species	Diameter class									Total
	6	8	10	12	14	16	18	20	22+	
					inches					
					1952					
Yellow-poplar	13.5	8.5	5.7	7.2	5.7	2.8	.6	.3	.5	44.8
Oak [2]	8.6	8.7	6.6	4.0	6.8	4.4	1.8	1.4	3.2	45.5
Red maple	6.9	5.4	1.5	1.1	.8	.6	.3	.1	--	16.7
Locust	--	1.2	.8	.5	1.1	.1	--	.1	--	3.8
Misc. [3]	6.8	.6	.8	--	.3	--	--	--	--	8.5
Total	35.8	24.4	15.4	12.8	14.7	7.9	2.7	1.9	3.7	119.3
					1954					
Yellow-poplar	11.4	7.1	6.6	1.2	--	--	--	--	--	26.3
Oak	8.3	7.0	4.9	3.5	1.4	--	--	.1	--	25.2
Red maple	5.8	3.5	.9	.5	.1	--	--	--	--	10.8
Locust	--	1.2	.8	.5	--	--	--	--	--	2.5
Misc.	5.9	--	--	--	.1	--	--	--	--	6.0
Total	31.4	18.8	13.2	5.7	1.6	--	--	.1	--	70.8
					1979					
Yellow-poplar	14.0	16.6	13.8	7.7	8.2	8.2	5.2	2.9	1.4	78.0
Oak	1.0	2.6	3.8	3.3	3.7	4.4	2.8	1.0	1.0	23.6
Red maple	3.7	5.2	5.8	2.6	2.1	1.7	.8	.5	.1	22.5
Locust	1.7	2.3	.5	.5	.5	.1	.1	--	--	5.7
Misc.	4.4	3.2	.8	1.1	.6	.1	.3	--	--	10.5
Total	24.8	29.9	24.7	15.2	15.1	14.5	9.2	4.4	2.5	140.3

1/ Based on 100-percent cruise by 2-inch diameter classes, i.e., 6-inch class includes trees 5 to 6.9 inches, etc.
2/ Predominately white oak with some black and northern red.
3/ Includes hickory, sweetbirch, sourwood, and others.

Table 2.--Stand conditions, per acre

Stand	No. of trees	Basal area	Volume
		---ft^2---	--fbm--
Original stand 1952	119	81	7,834
Residual stand 1954	71	26	288
Stand after 27 years 1979	140	110	8,023
Growth/acre/year		3.1	297

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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Harvesting rules called for removal of all yellow-poplar over 10 inches in diameter at breast height (d.b.h.) and other species over 12 inches. The harvest cut removed 51 trees with 7,546 board feet per acre. In 1954 the residual stand had 71 trees per acre--mostly less than 12 inches d.b.h. (table 1). Basal area averaged 26 square feet per acre and only 288 board feet of sawtimber volume remained. Of the residual stems over 6 inches d.b.h., 37 percent were yellow-poplar, 36 percent oaks, 15 percent red maple, and the remaining 12 percent were miscellaneous species such as hickory (Carya spp.), dogwood (Cornus florida), sourwood (Oxydendrum arboreum), etc.

A 100-percent cruise of the stand in 1979--27 years after the diameter-limit cut--showed a stand with 148 trees per acre with 110 square feet of basal area and 8,023 board feet of sawtimber (tables 1 and 2). Of those trees large enough to grade, 24 percent were grade 1, 39 percent grade 2, 32 percent grade 3, and only 5 percent cull. Since the diameter-limit cut, the stand had grown at the rate of 3.1 square feet of basal area and 297 board feet per acre per year--a very respectable showing! The stand gave all appearances of a vigorous, even-aged stand of mixed species composition.

THE PROBLEM

From the available records of the initial stand, cutting records, and residual stand in 1954, we could only speculate about the origin of the high-quality sawtimber trees that were present in 1979. Did they come from the trees 6 to 12 inches d.b.h. that were left? Were trees in that category intermediate and suppressed trees as would seem to be the case? Or were they younger, vigorous, developing trees that existed in openings? Or was the present stand derived from trees regenerating after the diameter-limit cut in 1952? Could we predict similar response for other stands cut in a similar manner?

In order to answer these questions, stem analysis was used to reconstruct the age and size distribution of the current stand at the time of the diameter-limit cut and to determine response to the cut.

METHODS

Plot Establishment

Four 1/5-acre circular plots were established in a stratified random manner to account for apparent site variation as indicated by topographic position and land surface configuration. Within each plot, all trees in the main canopy were tallied by species, d.b.h., total height, and tree grade. Each tree location was mapped by distance from plot center and azimuth. All understory trees over 4.5 feet tall were tallied by species and diameter.

Stem Analysis

After felling, each tree on the 1/5-acre plot was sectioned at breast height and intervals up the bole to the tip. Length of interval above breast height was 4 feet to the 16-foot level, and 8 feet thereafter. Ring counts and height aboveground were recorded for each section point. A disk removed at breast height was taken to the lab for ring counts and measurement under magnification. Growth measurements were made on six radii to account for eccentricities in growth.

Information generated for each tree from the stem analysis consisted of status at time of diameter-limit cut in terms of: age, d.b.h., total height, height growth for the 5 years before and after release, diameter growth for the 5 years before and after release, height and diameter growth for the 27 years after release.

RESULTS AND DISCUSSION

The four plots were similar in species composition, size, and age distribution. Therefore, plot data were combined for analysis and discussion.

Age Structure

Age (table 3) for the dominant stand (dominant, codominant, and intermediate crown classes) in 1979 ranged from 26 to 164 years. However, the ages were not randomly distributed over that range, but fell in some rather obvious groupings. Of 81 trees, 24 (30 percent) were less than 27 years old and originated as a result of the 1952 timber harvest. Yellow-poplar dominated this category. These trees were almost certainly of stump-sprout origin as attested to by height growth pattern, evidence of stumps, and other studies in the area (Beck 1977).

Table 3.--Age structure of dominant stand, 1979 1/

Age class	Yellow-poplar	Locust	Red maple	Oak	Hickory	All
< 27	21	3	--	--	--	24
31 - 40						--
41 - 50						--
51 - 60						--
61 - 70	10		5			15
71 - 80	9		4	2	1	16
81 - 90	5		6	--	1	12
91 - 100				1	2	3
101 - 110				2	1	3
111 - 120				3	1	4
121 - 130					1	1
131 - 140						--
141 - 150				1		1
151 - 160					1	1
161 - 170				1		1
Total	45	3	15	10	8	81

1/ Number of trees in intermediate, codominant and dominant crown classes on four 1/5-acre plots.

A second grouping of 43 trees (53 percent) consisted primarily of yellow-poplar and red maple 60 to 90 years old. The origin of these trees can be associated with a period around 1900 when the land was acquired by the Vanderbilt Estate, farming ceased, and fire protection begun.

The remaining 14 trees (17 percent) included oak and hickory and originated over a 90-year period beginning around 1810 when the land was first settled and cleared for agriculture. Historical records for the Bent Creek Experimental Forest suggest the land was subjected to grazing, burning, and periodic high grading throughout that period (Nesbitt 1941).

Size Structure

Height and diameter of the dominant stand in 1979 and as it existed in 1952 at the time of release is summarized by species in table 4. Despite the rather wide range in ages of the different species, the height of trees in 1979 in the dominant stand was similar, with species averages ranging from 85 to 92 feet. In terms of diameter, the oaks had a sizable advantage over all species except yellow-poplar stems already in place in 1952. A few of the yellow-poplar that originated as stump sprouts in 1952 developed into codominant crown positions. But for the most part, these younger trees were somewhat smaller than trees beginning as residuals, and they occupied an intermediate crown class position.

Table 4.--Size distribution of dominant stand, by species

Species	1979				1952			
	Height		D.b.h.		Height		D.b.h.	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
	- - ft - -		- inches -		- - ft - -		- inches -	
Oak	92	83-102	16.7	13.5-22.2	68	48-85	9.9	4.4-12.3
Hickory	87	74-113	11.0	7.9-19.4	55	37-94	6.2	4.2-11.5
Red maple	85	66-110	13.0	7.6-22.0	47	23-85	6.0	1.7-13.1
Yellow-poplar								
Residuals	100	74-122	15.9	7.5-22.0	57	16-92	6.5	2.2-11.3
New	82	66- 96	9.4	5.8-15.1	--	--	--	--
All	92	66-122	12.9	5.8-22.0	--	--	--	--

The average size of oak trees in 1952 was larger than that of other species. Over 80 percent of the oaks were larger than 7 inches d.b.h. and over 50 feet tall when released. Most would appear to have occupied intermediate crown classes before release. Hickory had a wide range of sizes but were mostly less than 5 inches d.b.h. and less than 50 feet tall. Red maple and yellow-poplar showed the widest range in size of responding trees. But they too were concentrated in the smaller size classes. Some trees that were 11 to 12 inches d.b.h. and over 80 feet tall probably were strong intermediates or possibly codominants before the diameter-limit cut. Others that were 2 to 3 inches d.b.h. and less than 25 feet tall at 30 to 40 years of age could only have been severely suppressed trees. If grown unrestricted, yellow-poplar of the same age could easily obtain a height of 80 to 90 feet and 13 to 15 inches d.b.h. Red maple would be only slightly smaller. Over 40 percent of the responding yellow-poplar were less than 5 inches d.b.h. and 50 feet tall with a range in ag from 35 to 50 years. A good share of the responding yellow-poplar and red maple were probably suppressed trees.

Growth Response

In order to examine growth response, I compared height and diameter growth for the 5-year periods before and after release (tables 5 and 6). The diameter growth is for wood only and does not include bark.

Table 5.--Five-year diameter growth before and after diameter-limit cut

Species	Before cut		After cut		Percent increase
	Mean	Range	Mean	Range	
	- - - - - - - - -	inches	- - - - - - - - -		
Oak	.52	.18- .99	1.56	.86-2.45	200
Hickory	.29	.13- .65	.95	.16-1.24	228
Red maple	.44	.13-1.22	1.53	.55-2.47	248
Yellow-poplar	.57	.24-1.51	1.84	.28-3.00	223

Table 6.--Five-year height growth before and after diameter-limit cut

Species	Before cut		After cut		Increase
	Mean	Range	Mean	Range	
	- - - - - - - - -	feet	- - - - - - - - -		
Oak	3.0	2 - 4	3.2	2 - 5	7
Hickory	2.4	1 - 4	4.0	2 - 6	67
Red maple	3.3	1 - 8	6.7	2 - 19	103
Yellow-poplar	3.3	1 - 7	6.3	2 - 19	91

Rate of diameter growth prior to release was extremely slow for all species, reaffirming the poor competitive position of the trees. Hickory, the slowest grower, averaged nearly 35 rings per inch. Yellow-poplar, the fastest, averaged nearly 18 rings per inch prior to release.

Diameter growth response was immediate and dramatic for all species, ranging from a 200-percent increase for the oaks to a 248-percent increase for red maple. After release, diameter growth rates ranged from 0.95 inches in 5 years for hickory to 1.84 inches for yellow-poplar. These rates are comparable to those for good-vigor trees of similar species and size.

Height growth response in the first 5 years after release was not as great as diameter response and was more variable among species. The oaks increased in height only slightly. The small response is not surprising because the trees had already obtained a considerable part of the height potential for the site at time of release. Red maple and yellow-poplar nearly doubled their rates of height growth on the average. Many of the shorter trees (20- to 30-foot class) of these species grew three to four times faster after release.

The total amount of height growth in the 27 years since release varied from an average of 24 feet for the oaks to 45 feet for yellow-poplar (table 7). Yellow-poplar presents a particularly interesting case. The amount of growth was inversely proportional to the height at time of release (fig. 1). The rate of height growth after release was close to that expected of trees of a similar height but much younger age and which have always been in a dominant or codominant position (Beck 1962). Age of tree, per se, had little effect on the rate of growth. Figure 2 shows representative height growth patterns for some individual trees that were a) suppressed residuals at time of diameter-limit cut, and b) stump sprouts originating at time of the cut. Note the similarity of growth patterns between residuals after release and stump sprouts.

Table 7.--Total growth for 27-year period after release by diameter-limit cut

Species	Height		D.b.h.	
	Mean	Range	Mean	Range
	- - - feet - - -		- - inches - -	
Oak	24	17-37	7.6	5.6-10.5
Hickory	33	19-45	5.1	2.9- 7.9
Red maple	38	12-56	7.0	3.4-11.4
Yellow-poplar 1/	45	23-76	9.5	3.8-15.8

1/ Includes only those trees established prior to the cut.

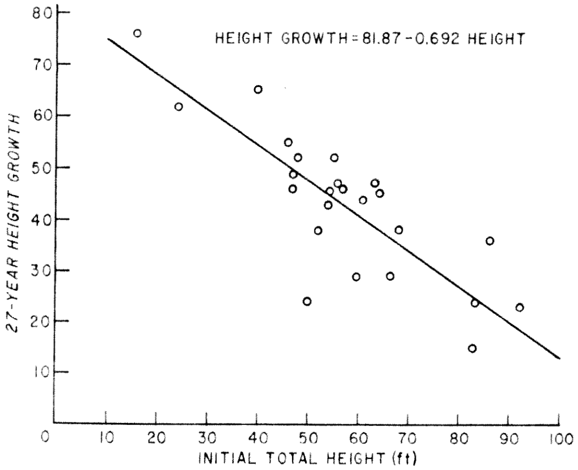

Figure 1.--Height growth of yellow-poplar in relation to initial height.

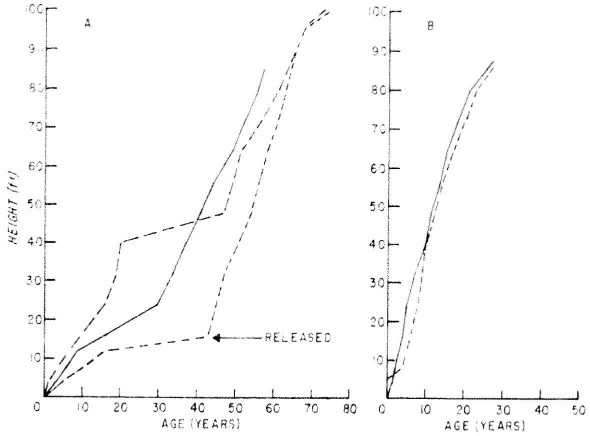

Figure 2.--Height growth of selected yellow poplar (a) residuals, (b) stump sprouts.

SUMMARY AND CONCLUSIONS

A diameter-limit cut which removed yellow-poplar trees over 10 inches d.b.h. and other species larger than 12 inches resulted in a mixed stand of good quality and high vigor 27 years later. Through complete stem analysis of all trees on four 1/5-acre plots, I was able to reconstruct the status of surviving trees at the time of the harvest cut.

A portion of the 1979 stand (30 percent) was made up of yellow-poplar that originated as stump sprouts after the diameter-limit cut. Some of these trees attained codominant crown status, but most were in an intermediate position. The remainder of the stand (70 percent) resulted from trees present at time of the cut. Trees from wide ranges of age, d.b.h., and height responded to release. The oaks and hickory that responded averaged nearly 80 years of age; some were over 150 years old. Yellow-poplar and red maple were mostly 50 to 60 years old at time of release. Response occurred in trees from less than 2 to greater than 12 inches and from 16 to 92 feet in height.

A few of the larger poles that responded may have been codominant crown classes before release. However, size, age, and rates of growth suggest that most trees were suppressed and intermediate crown classes. Regardless of age and size, response to release was immediate for all species involved. Growth rates after release were comparable to what might be expected of trees of equal size but of much younger ages. The quality of sawtimber trees is good. Rapid height growth of responding trees and new stump sprouts apparently formed a closed stand quickly, promoted natural pruning, and prevented development of wolf trees.

The results of this study parallel the findings of Smith and Lamson (1977) for a similar diameter-limit cut in West Virginia. In their study a stand dominated by oak species was cut to a 9-inch diameter. The residual stand of 110 trees per acre in the 5- to 9-inch diameter classes developed into a well-stocked stand with 7,425 board feet of sawtimber per acre in 25 years. They speculated that most of the sawtimber developed from the pole-size material left after the logging. It should be noted that in both cases a good number of poles of desirable species were present in the residual stand. Also both sites were of good quality for tree growth.

We should not assume that all upland hardwood stands will respond as favorably as this one. Nor should we recommend diameter-limit cuts as a standard operating procedure. In fact, there are undoubtedly instances where repeated diameter-limit harvests have caused deterioration of both quality and quantity of growth. However, the response here suggests that it may not always be necessary to follow current recommendations to cut or kill all residual stems over 1 or 2 inches d.b.h. during clearcut harvesting. There may be other situations where saplings and poles capable of response are present in sufficient numbers after commercial harvests to provide acceptable growth and quality. We need further information on different sites with varied stocking conditions and species combinations to define those conditions and to establish guidelines.

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GROWTH AND YIELD PREDICTIONS FOR LOBLOLLY PINE--THE COOPERATIVE RESEARCH PROGRAM AT VIRGINIA TECH[1]

Ralph L. Amateis

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Abstract.--The Loblolly Pine Growth and Yield Research Cooperative was initiated at Virginia Tech in 1979 to develop the methodology necessary to accurately predict growth and yield in intensively managed loblolly pine plantations. This paper summarizes research completed since inception of the Cooperative and reports progress on current studies and proposed future research.

INTRODUCTION

The last several years have witnessed notable advances in growth and yield prediction methodology. Many of these new techniques have been successfully applied to forest stands in the Southeast. However, adequate predictions for the wide range of management and utilization options that managers now wish to evaluate are not available. Management options such as thinning, site preparation, fertilization and the planting of genetically superior stock require accurate growth and yield response data for evaluation. In addition, changing utilization standards have magnified the need for added flexibility in growth and yield modeling. Flexible prediction techniques adaptable to a variety of product mixes are essential.

In light of the urgency for more reliable prediction techniques and the scope of the task, the Loblolly Pine Growth and Yield Research Cooperative was initiated at Virginia Tech in 1979. The Cooperative is currently comprised of ten private industrial firms and three public agencies.[3]

Funds supplied by the cooperators support one full time research associate and several graduate research assistants. In addition to financial support, cooperators contribute data for growth and yield modeling and validation and assist in defining pertinent research emphases.

Dealing strictly with loblolly pine, the Cooperative's objectives are two-fold:

1. The major long-term goal involves developing the methodology necessary to accurately assess growth and yield in intensively managed loblolly pine plantations. This necessitates a continuum of data collection, analysis and interpretation. As research reveals knowledge gaps, additional studies can be designed with appropriate data collection efforts.

2. The interim short-term goals consist of utilizing available data to supply cooperators with suitable solutions until long-term objectives can be achieved. This often includes searching various sources, both within and without the Cooperative, for pertinent data.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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[3] Industrial members are Bowater Incorporated, Champion International, Chesapeake Corporation of Virginia, Continental Forest Industries, Crown Zellerbach, Federal Paper Board Company, International Paper Company, Potlatch Corporation, Westvaco Corporation and Weyerhaeuser Company. Public agencies include the U.S. Forest Service and the North Carolina and Virginia Divisions of of Forestry.

The purpose of this paper is to summarize recent research completed since inception of the Cooperative and report progress on current studies and proposed future research.

PREDICTING CONTENTS OF INDIVIDUAL TREES

Over the last several years, various models have been developed for predicting merchantable volume of individual trees. The models fall into one of two categories: taper equations, which when integrated between limits of height and diameter will yield volume of any particular portion of the bole, and volume ratio models which predict some merchantable volume as a ratio of total volume.

Under the Cooperative, development and testing of these types of models are continuing. Cao *et al*. (1980) examined several different taper equations and volume ratio equations. Each model was evaluated in terms of cubic foot volume and diameter prediction and each was ranked according to the following three criteria:

1. Bias - the mean of the differences between the actual and predicted values.

2. Mean absolute differences - the mean of the absolute differences.

3. Standard deviation of the differences.

Their results show that the choice of an appropriate model depends on the objective. For describing tree taper, a segmented polynomial (Max and Burkhart 1976) was deemed best. For predicting merchantable volume to a specified top diameter or height, the nonlinear volume ratio models (Burkhart 1977 and Cao *et al*. 1980) were judged superior. A model which does well at predicting both diameters and volumes is a new taper equation of the form:

$$(d^2KH/V-2Z)=b_1(3Z^2-2Z)+b_2(Z-a_1)^2I_1+b_3(Z-a_2)^2I_2$$

where

d= diameter at height h
H= total tree height
Z= $(H-h)/H$
V= total tree volume
K= 0.005454 if d is in inches and V in cubic feet
a_1, a_2 = join points
I_i= 1 if $Z \geq a_i$; $i=1,2$,
= 0 if $Z < a_i$.

The precision with which tree taper can be predicted based only on dbh and total height is, however, limited due to other influencing factors. Cultural practices such as thinning and pruning affect tree taper with thinning generally tending to increase taper and pruning fostering more cylindrical stems (Larson 1963, Kozlowski 1971). These practices directly affect crown size. As a result, the Cooperative recently supported work which examined relationships between crown ratio and tree taper.[4]

This research effort was a two-pronged study, first examining the possibility of including crown ratio to improve the precision of diameter prediction from taper equations and secondly, studying the effect of different silvicultural treatments on bole form. Data for the first study came from unthinned old-field loblolly pine plantations in North Carolina, Virginia, Maryland and Delaware. Data used in the analysis of treatment on bole form came from the North Louisiana Hill Farm Experiment Station in Homer, Louisiana. These data consist of plots treated with thinning, pruning, thinning and pruning, and control.

Conclusions resulting from this study were:

1. Crown ratio is related to tree taper, but, for many practical situations, the relationship is not strong enough to warrant the extra effort and expense required to include it as an independent variable in a taper equation.

2. In untreated stands, stand variables such as age, site index and number of trees per acre have relatively little impact on tree taper. Therefore, equations using dbh and total height as independent variables are sufficient to predict tree taper over a wide range of stand characteristics.

3. When measured several years after treatment, little difference in bole form between thinned, pruned, or thinned and pruned loblolly pine was found. Using separate taper equations for trees subjected to these treatments does not appear to be justifiable under many practical circumstances.

POLYMORPHIC SITE INDEX CURVES

Devan (1979) derived base-age invariant polymorphic site index curves for planted and natural stands of loblolly pine.[5] The objective of the study was to develop an improved site index model for loblolly pine. The new model was then compared to other existing models for accuracy, precision and logical characteristics.

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[4] Burton, Sally S. 1980. The influence of crown ratio on taper predictions of loblolly pine (*Pinus taeda* L.). Unpublished Masters Thesis, Va. Polytech. Inst. & State Univ., Blacksburg, VA.

[5] Devan, James S. 1979. Base-age invariant polymorphic site index curves for loblolly pine. Unpublished Masters Thesis, Va. Polytech. Inst. & State Univ., Blacksburg, VA.

Data for the study were obtained from 356 plots of natural and planted stands of loblolly pine in Virginia, North Carolina, Maryland and Delaware. Statistical tests showed separate equations were needed for the following groups:

1. natural stands
2. plantations on cutover sites
3. plantations on old-field piedmont sites
4. plantations on old-field coastal plain sites.

In order to fit the data, a segmented model was developed which joins two separate models - one for younger ages and one for older ages. The following model, modified from Lenhart (1968)[6] was applied:

$$\frac{dy}{dx} = b_0+b_1x+b_2x^2+b_6y \qquad X \leq L$$

$$= b_3+b_4x+b_5x^2+b_6y \qquad X > L$$

where

L = 1/join point age

$\frac{dy}{dx}$ = instantaneous rate of height growth

y = ln (height)

x = 1/Age

Independent data were available for evaluating the curves for old-field plantations. These independent data consisted of 27 trees from permanent plots on old-field piedmont sites in Virginia. Measurements were recorded three times usually at five-year intervals beginning at age 12, 13 or 14. Using these data, the join point model was compared to anamorphic curves in Burkhart et al. (1972) and polymorphic curves in Burkhart (1973)[7] Results showed the new join point model underestimated the site index by an average of less than two feet over roughly a ten-year span. The anamorphic curves (Burkhart et al. 1972) were next best and underestimated the site index by an average of 8.8 feet. The polymorphic curves of Burkhart (1973) underestimated site index by an average of 9.7 feet.

No independent data were available for evaluating the natural stand or cutover site plantation curves. However, the natural stand curves did appear to exhibit logical trends but the cutover site plantation curves, which were based on an extremely small sample size from young plantations, appeared to "flatten" at too early an age. In general, the polymorphic curves for old-field plantations and natural stands are somewhat "steeper" than most published site index curves for comparable conditions.

STAND GROWTH AND YIELD

Assembly of Existing Data

The Loblolly Pine Growth and Yield Research Cooperative memberships' landholdings stretch across the natural range of loblolly pine. The diversity of sites and climatic conditions is enormous, making the task of developing relevant growth and yield predictions complex. In order to meet the immediate needs of cooperators for growth and yield prediction models for stand characteristics that are applicable across a wide variety of sites, data representative of these sites were assembled from various locations in the Southeast. Table 1 summarizes these data.

Table 1. Data sets currently being analyzed by the Loblolly Pine Growth and Yield Research Cooperative.

Cultural Treatment	Type	Physiographic Region	Geographic Location by State
Unthinned	old-field	coastal plain-piedmont	VA, MD, DE, NC
Unthinned	old-field	coastal plain	MS, AL
Unthinned	old-field	coastal plain	TX, AR, LA
Unthinned	old-field	piedmont	GA
Thinned	old-field	coastal plain-piedmont	VA
Thinned	old-field	coastal plain-piedmont	NC, SC, GA, VA, MD

The unthinned old-field data are representative of much of the natural range of loblolly pine. These data, which are primarily from several earlier studies on yield in unthinned old-field plantations, have been generously supplied

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[6] Lenhart, J. D. 1968. Yield of old-field loblolly pine plantations in the Georgia piedmont. Ph.D. Dissertation, University of Georgia, Athens, GA.

[7] Burkhart, H. E. 1973. Site index curves from stem analysis data. Supplement to VPI-Industry Cooperative Yield Study Rept. #6, unpublished memo.

by the originators of the studies.[8/] They should provide insight into the regional variability of the species and aid in the design of future data collection efforts.

A large data set from thinned, old-field plantations has been supplied to the Cooperative by the Virginia Division of Forestry for analysis and research purposes. These data come from over 100 remeasurement plots on private landholdings in piedmont and coastal plain Virginia. Many of these plots are now approaching 50 years of age. All have been thinned at least once and several have been subjected to multiple thinnings. Variables recorded include dbh by one-inch classes, total height and mortality by causal agent. These data have not been analyzed previously and hopefully will add insight into the effects of thinning on old-field plantation growth and development.

Additional data from thinned old-field stands in Maryland, Virginia, North Carolina, South Carolina and Georgia have been obtained through a cooperative agreement with the North Carolina State Forest Fertilization Cooperative. These plots were initially thinned and then individual trees were measured and tagged. Subsequent remeasurements occurred after two and after four years.

Past studies on growth and yield of unthinned, old-field loblolly pine plantations have largely covered the natural range of the species (for example, Burkhart _et al._ 1972, Goebel and Warner 1969, Lenhart 1972, Lenhart and Clutter 1971, and Smalley and Bailey 1974), but there is relatively little data on thinned stands or stands planted on non-old-field sites. The Loblolly Pine Growth and Yield Coop is currently analyzing those plot data that are available from thinned stands on old-field sites and making plans to collect new data in cutover, site-prepared plantations.

Proposed New Data Collection

Our surveys of existing data from loblolly pine plantations have revealed adequate sources for old-field sites but there is a paucity of data from cutover, site prepared lands. For over a decade a large portion of the plantings have been on cutover rather than old-field lands. Many of these plantations on cutover sites are now of sufficient size to consider thinning, but adequate growth and yield models for evaluating the complex biological and economic tradeoffs involved in decisions about thinning are not available.

Because of the importance of growth and yield information for both thinned and unthinned plantations on cutover lands, the Cooperative has developed plans for a regionwide set of permanent plots. These plots will be established in unthinned stands and then thinning treatments will be imposed. Initial measurements and remeasurements of the control plots will provide data for the development of growth and yield equations for unthinned conditions. The plots that will be thinned will have initial conditions similar to those of the control plots. Thus, direct comparisons of thinned vs unthinned stand development should be possible.

As a future data collection goal, we hope to supplement the data gathered in existing plantations with a set of spacing experiments. Designed spacing experiments are needed to help define juvenile growth and mortality, optimal density for given product objectives, and density effects on diameter and height growth. Information on density effects on height growth can be invaluable for assessing the adequacy of our current site index methods which assume density independence.

Few spacing experiments have been initiated and monitored over long periods of time because of the large land area and quantity of work required. The broad resources of land and personnel that are available to the Cooperative through its members provide a unique opportunity to initiate and continue such a study.

Prediction Methodology

Although a considerable amount of forest yield research has been conducted, there is still a need for better yield estimates. Projection systems that are flexible for a wide range of management alternatives and utilization options, and that provide consistent and logical estimates of yield for varying amounts of stand detail, are needed. Daniels _et al._ (1979) compared three models for loblolly pine -- a whole stand model, a diameter distribution model, and an individual tree model -- and noted that all performed similarly for simple yield estimates. The more detailed individual tree model, while providing greater detail and flexibility, was much more expensive to execute than the diameter distribution or whole stand models. Although guidelines are given for the efficient use of these models, there is no overall unifying structure and incompatible growth and yield estimates may result when the models are interchanged.

The Loblolly Pine Growth and Yield Coop at Virginia Tech is striving to develop a forest growth and yield projection system that is sufficiently flexible to account for the effects of intensive cultural practices, with output sufficiently detailed (complete diameter and height distributions) to allow for analyses of a full range of utilization options. This system should

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[8/] The cooperation of Drs. Russell Ballard, North Carolina State University; Jerome L. Clutter, University of Georgia; J. David Lenhart, Stephen F. Austin State University; and Alfred D. Sullivan, Mississippi State University, in supplying data for use in regional analyses is gratefully acknowledged.

be capable of providing logical and consistent estimates of growth and yield for varying degrees of stand detail (whole stand values, estimates by diameter class, or individual tree figures), thus allowing users to efficiently compute estimates with stand detail appropriate to the use of the information.

The highest order model (i.e, greatest amount of detail or resolution) will have a structure similar to that of the loblolly pine plantation simulator published by Daniels and Burkhart (1975). In such a model, the diameter growth, height growth, and survival probability of individual trees are simulated as a function of an initial growth potential and an index of competition from neighbors. The competition index, based on a function of the size of and distance to surrounding trees, is a measure of the degree to which growth resources may be limited by the number and proximity of neighbors.

When progressing from a distance-dependent individual tree model to one that does not require information on intertree distances, some stand-level generalization of the individual tree competition index is needed. One index that has a readily interpretable stand-level generalization is the area potentially available (APA) (Brown 1965, Moore et al. 1973). To compute APA, polygons are constructed around each tree by the intersection of lines which divide the distances between neighbors. Mean APA, or average area per tree, is estimated by the inverse of the number of trees per unit area. The use of APA as an individual tree competition model and trees per acre as the stand-level generalization is currently being investigated.9/

Bailey (in press)10/ has recently shown that, by considering transformations of variables which preserve an assumed probability density functional form for describing diameter distributions, tree diameter growth models can be derived. These results provide a link between tree-level growth models and stand level diameter distribution models. In 1975 Strub and Burkhart (1975) derived a class-interval-free method for obtaining expected yields from diameter distributions, thus providing a mathematical link between diameter distribution and whole stand modeling approaches. These results, along with those from current research, will be applied when completing the integrated spectrum from an individual tree model with intertree distances specified, to an individual tree model without intertree distances required, to a diameter class model, to a whole stand model.

We are also conducting research on deriving diameter distributions (which can be approximated with a probability density function) from stand average parameters. This will allow approximation of a diameter distribution when only overall stand values such as total cubic volume and total basal area are known.11/ Flexible methods for describing diameter distributions are also being investigated. Although probability density functions provide good approximations of diameter distributions in unthinned stands, they are not, in general, sufficiently flexible to account for all of the distributional shapes that can be created through thinning.12/

SUMMARY

The Loblolly Pine Growth and Yield Research Cooperative at Virginia Tech consists of 10 industrial forestry firms and three public agencies. The objective of the Coop is to develop growth and yield methodology and estimates for intensively-cultured loblolly pine stands.

Existing data sources appear to be adequate to develop yield predictions for unthinned and thinned plantations on old-field sites. However, new data collection efforts are deemed essential to develop adequate predictions for thinned and unthinned plantations on cutover site-prepared lands. In addition to data collection in existing plantations on cutover sites, plans are being developed for a set of designed spacing experiments.

New methodology being developed in the Growth and Yield Coop centers around an integrated system of stand models that will allow consistent and logical estimates of yield for varying amounts of stand detail. A system capable of providing consistent estimates of growth and yield for varying degrees of stand detail (whole stand values, estimates by diameter class, or individual tree figures) would allow users to efficiently compute estimates with stand detail appropriate to the use of the information.

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11/ Research being conducted by James R. Frazier, Graduate Research Assistant, VPI & SU.

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WHAT MEASURE OF STAND DENSITY IS BEST FOR GROWTH PREDICTIONS IN LOBLOLLY PINE PLANTATIONS[1]

H. Lee Allen and Howard W. Duzan, Jr.[2]

Abstract.--Stand density measures previously used for loblolly pine stands are reviewed and their ability to predict growth is compared. Because of its practical and theoretical advantages basal area is recommended as the measure of density for use in growth and response models. A stocking guide based on maximum net volume growth and basal area is presented.

INTRODUCTION

As the demand for wood products grows and the land base on which to produce the wood resource continues to diminish, management intensity is of necessity increasing. Silvicultural practices such as fertilization and thinning are becoming more prevalent in pine plantations throughout the South. An important aspect of intensive management is the development of models that predict the effect of various silvicultural treatments on growth and subsequent yield. The knowledge gained from these models will allow forest managers to apply the appropriate treatment to stands so that the maximum returns are realized.

The two most important factors influencing growth and response potential in established stands are stand density and site quality. It is essential that the measures used to quantify these factors are accurate and meaningful. This paper will consider the problems associated with measures of stand density.

When considering stand density or stocking (a relative measure of a "proper" stand density), two questions arise. First, which stand density measures will adequately delineate stands having the same competitive status over a range of sizes and number of stems? Second, how does growth response vary across stocking levels and what is the optimum density for a given silvicultural treatment?

CURRENT MEASURES OF STAND DENSITY

Over the years many measures of stand density and stocking have been developed for use in loblolly pine (Pinus taeda L.) stands. Some of the more common ones associated with tree diameter or number of stems include basal area, number of stems, and stand density indexes developed by MacKinney and Chaiken (1935), Stahelin (1949), and Westvaco[3]. The development of most measures of stand density are based on the premise that a relationship exists between crown diameter or area and competition. Various techniques are then used to transform this relationship into a number of stems-diameter expression.

Reineke (1933) was one of the first investigators to approach the problems of accurately defining stocking of even-aged stands. The stand density index developed by MacKinney and Chaiken (1935) was an adaption of his ideas specifically to loblolly pine. In 1940, Chisman and Schumacher (1940) proposed a tree-area ratio as a measure of density. Stahelin (1949) used this ratio to develop his stand density index. More recently, Westvaco[3] has developed a stocking chart based on a crown diameter-dbh relationship for trees in fully-stocked stands.

Although the forms of the stand density indexes vary, they can be easily compared by presenting them as number of stems-diameter relationships

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[3] Owens, E.G. 1970. Loblolly Pine Stocking Westvaco Research Report 47. Summerville Research Center, Summerville, SC (unpublished).

(fig. 1). For comparison purposes the stand density curves are represented by what their respective authors deemed as fully or 100% stocked. The shape of the curves (fig. 1) reflect the number of stems-diameter conditions which represent equal competitive status (question 1). These equi-competition curves represent various levels of stocking and are used to describe an optimal level for various silvicultural practices (question 2).

The shape of the equi-competition curves or stocking lines is very important since this shape determines how stands in different stages of development are classed as being of the same competitive status. The derivation of this shape for all the present stand density indexes is based on empirically derived relationships using data collected in subjectively chosen fully-stocked stands. Obviously any bias in selecting fully-stocked stands over the range of sizes and number of stems would influence the shape of the curves. It seems plausible that some underlying biological relationship would define the shape of these curves and would remove the necessity of fitting them with data from a subjectively determined stocking level.

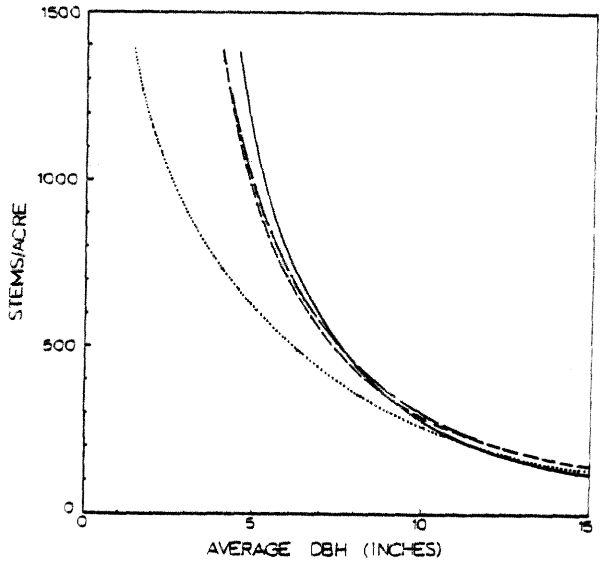

Figure 1.--Comparison of stand density indexes at fully stocked conditions:
– – – MacKinney and Chaiken (1935),
— — Stahelin (1949),
·········· Westvaco (Owens, Unpublished),
——— Basal area of 150 ft^2/acre.

EQUI-COMPETITION CURVE SHAPE DERIVATION

The concept of the -3/2 power law or dimensional analysis recently introduced into the American forestry literature (Drew and Flewelling, 1977) provides a theoretical framework for defining the shape of these curves. The approach used in this paper follows that of Drew and Flewelling (1977).

Ground area (GA) for an individual tree is proportional to the inverse of the number of trees per acre (N) and also proportional to a length (L) squared.

$$GA \propto 1/N \qquad (1)$$
$$GA \propto (L)^2 \qquad (2)$$

Tree diameter (D) is proportional to a length.

$$D \propto L \qquad (3)$$

It then follows that:

$$GA \propto (D)^2 \qquad (4)$$

Substituting 1/N for GA (equation 1), equation 4 may be rewritten as:

$$N \propto (D)^{-2} \qquad (5)$$

Statistically this may be expressed as:

$$N = K(D)^{-2} + \text{error} \qquad (6)$$

where K is a proportionality constant. Transformed, equation 6 becomes:

$$\text{Log}N = K' - 2\text{Log}D \qquad (7)$$

This is recognizable as the same form of MacKinney and Chaiken's (1935) stand density index except that the slope is a theoretically defined -2 instead of MacKinney and Chaiken's (1935) empirically derived slope of -1.707. The K' component determines the level of the curve and sets the standard reference for determining the number of stems at a given stocking level for a particular average tree size.

Since basal area (BA is proportional to average diameter, equation 7 can be expressed as:

$$\text{Log}N = K'' - \text{Log}BA \qquad (8)$$

On a theoretical basis equations 7 and 8 define the shape of the number of stems-diameter relationship as the square of diameter or more specifically curves of equi-competition have the same basal area.

Theoretically from dimensional analysis, it appears that basal area is a suitable method of delineating stands with equi-competition or of the same stocking level. Traditional criticisms of basal area as a measure of stocking are: 1. basal area is one dimensional and does not adequately describe the relationship between number of stems and diameter, and 2. basal area should increase as tree size increases at a given stocking level. Referring to figure 1 it is apparent that basal area is two dimensional and expresses a dimensional relationship between number and size of stems. In fact, two of the empirical measures closely follow the basal area trend (fig. 1). For some species basal area may be expected to increase as tree size increases for a given stocking level as some of a tree's basal area becomes nonfunctional. This is borne out in studies that have shown that sapwood area may be a better estimator of foliage biomass (growth potential) than simply diameter or basal area (Grier and Waring, 1974; Snell and Brown, 1978). For loblolly pine of the size and age range found in managed plantations, total basal area is generally equivalent to sapwood area.

UTILITY IN GROWTH PREDICTIONS

Putting theoretical considerations aside, which of the stand density measures will best predict growth response?

Three growth models were used to compare the utility of each stand density measure for predicting gross growth of untreated stands.

(A) $\text{Gross Growth} = a + b\,(SD)$

(B) $\text{Gross Growth} = \dfrac{a + SD}{b + c(SD)}$

(C) $\text{Gross Growth} = \dfrac{a + SD}{b + c(SD) + d(SI) + e(SD * SI)}$

where SD = stand density measure, SI = site index (25 years), and a, b, c, d, e are coefficients estimated from the data.

The models were fit using 5-year growth data from 247 control plots selected from the North Carolina State Forest Fertilization Cooperative's first and second regional trial series. This data set covers the range of ages, densities, and site classes commonly found in managed loblolly pine plantations. The data set and models B and C are described in greater detail in another paper presented at the symposium (Duzan and Allen 1980). The coefficients of determinations for these three models using the various stand density measures are as follows:

	-----------Model-----------		
	A	B	C
Basal Area	44.6	47.5	65.7
MacKinney and Chaiken (1935)	45.0	48.1	67.0
Stahelin (1949)	45.0	48.3	67.7
Westvaco[3/]	42.9	46.9	70.0
Number of Stems	16.8	8.1	34.1

All stand density measures, except number of stems performed equally in predicting 5-year gross growth of untreated stands. Nelson and Brender (1963) reported similiar results in their comparison of stand density measures. From a practical aspect, basal area is superior since it is easily understood, easily measured, and normally available for most managed plantations. Because of its theoretical and practical advantages, basal area is recommended as the standard for quantifying stand density in loblolly pine plantations.

OPTIMUM STOCKING LEVELS

Answering the second question of what stocking level is optimum for a given silvicultural treatment is more complex. The optimum stocking can be expected to vary depending on the treatment, site quality, response period, and management objectives. As a first approximation, a stocking guide based on maximum 5-year net volume growth and initial basal area is presented in table 1. A model estimating the ratio of 5-year mortality volume to 5-year gross volume growth as a function of basal area was used in conjunction with the gross growth-basal area-site index model to predict 5-year net volume growth.

This stocking guide delineates the basal area at which maximum net growth is realized in untreated plantations. Depending on the silvicultural treatment imposed, basal area as a measure of stand density may or may not reflect the potential for growth response in treated stands. For those treatments which do not substantially alter a stand's natural competitive structure, such as nitrogen fertilization, the stocking guide should be applicable for determining those stand conditions where maximum net volume growth occurs. However, if a stand's natural competitive structure was altered, as with thinning, basal area may not adequately express a stand's competitive condition after treatment. The deviation in volume growth of a thinned stand from that of an untreated stand of the same basal area will be a function of the type of thinning, thinning intensity, residual spacing, and the amount of damage to the site and residual trees during the thinning operation. Adjustment factors to compensate for these effects are discussed in more detail in another paper presented at this symposium (Ballard et al, 1980). After thinning, a stand will readjust to a more natural competitive status over time. Consequently, the deviation in growth of a thinned stand from that expected for an untreated stand will decrease over time and an adjustment factor may not be necessary for stands thinned several years previously.

If the stocking guide (table 1) was presented in the traditional number of stems-diameter format, it would be immediately apparent that the stocking levels are not proportional as typically portrayed in stocking charts. In fact, basing stocking on percentage of maximum net growth attainable, a large range of basal area provides the necessary resource to maintain stocking at 90 percent.

The basal area associated with maximum net growth decreases as site index increases. At first glance, this would appear to be contrary to what is normally expected. It is important to distinguish between the concepts of what basal area a given site can support and what basal area provides for maximum net growth. In the case of managed loblolly pine plantations, the basal areas associated with each concept probably differ; in fact, stands on higher sites would normally support greater basal areas.

CONCLUSIONS

Basal area is recommended as the measure for quantifying stand density in the development of growth prediction models for untreated loblolly pine plantations. Basal area has practical and theoretical advantages as a measure of stand density which are unequaled by any other currently used index. The use of basal area will provide an easy means of developing stocking guides based on different growth or response criteria using models currently available in the literature. A stocking guide developed using the percentage of maximum 5-year net volume growth attained as a stocking criteria illustrates that 90 percent stocking is associated with a wide range of basal areas. The basal area of a 100 percent stocked stand also decreases as site index increases. The stocking guide presented has been developed for growth prediction in untreated stands. The guide should still be valid for stands receiving treatments which do not substantially alter the natural competitive structure of a stand such as N. fertilization. However, the use of the stocking guide for stands receiving treatments which do substantially alter their structure, such as thinning, may not be valid.

Table 1.--Basal area stocking guides based on maximum five-year net volume growth for loblolly pine by site index class (25 year).

Percent of Maximum Net Growth	Site Index Class (ft)			
	50	60	70	80
		ft^2/acre		
50	10	10	10	5
60	20	20	15	10
70	30	30	25	20
80	45	40	40	35
90	70	65	60	55
100	125	125	120	115
90	180	180	180	175
80	200	200	200	195

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A COMPETITION FUNCTION FOR TREE AND STAND GROWTH MODELS[1]

William R. Harms[2]

Abstract.--A two term function is described that is significantly correlated with annual diameter growth of individual loblolly pine *(Pinus taeda* L.*)* trees. One term expresses competition in the whole stand; the other is a measure of the competitive advantage of individual trees. The function operates by reducing the effective growing space of a tree, defined as the space available per tree in stands that are actively self-thinning.

INTRODUCTION

Computer simulation is a relatively new technique for studying tree growth and stand development. Mathematical models are the heart of simulation, and, of the types that have been proposed, the more interesting and useful project growth of individual trees rather than the entire stand. There are two types of these single-tree models: one requires information about the physical location of each stem in the plot or stand and is called a distance-dependent model; the other requires only a list of tree diameters and is called a distance-independent model (Munro 1974).

Both single-tree models project growth of individual trees according to some function of their size and competitive status in the stand. One approach is to adjust an assumed or estimated potential growth rate for a tree of given age or size by a component that gauges the intensity of competition. Another approach is to predict actual growth with a regression equation that contains a competition component.

In the distance-dependent model this component may be a competition index that relates d.b.h. or crown size to distance between the subject tree and its competitors. The competitors are chosen by a rule based on size and distance from the subject tree. In the distance-independent model the competition component usually expresses the relative position of a tree in the stand based on its d.b.h. in relation to some reference d.b.h.

The component that estimates competition is an essential part of single-tree models. It controls diameter and height growth and helps determine mortality. Various forms have been proposed, but none have yet proved to be entirely satisfactory (Alder 1979, Alemdag 1978, and Daniels 1976). All have failed to predict diameter growth with the desired precision and accuracy.

In this paper, I describe a new measure of competition. It is a mathematical function for the distance-independent model, but it also can be adapted to distance-dependent models. Development of this function is in a preliminary stage but, as the correlation data given below show, it has promise of becoming a useful addition to growth modeling.

THE COMPETITION FUNCTION

Underlying assumptions for the function are: (1) rate of growth depends on growing space, S_i, and (2) competition from its neighbors reduces the effective growing space of a tree to a fraction of the space available to it. The function, $f(S_i)$, estimates this fraction; for the ith tree, diameter growth, DG, can be estimated by a regression equation of the form:

$$DG_i = b_0 + b_1 (S_i)(f(S_i)) \qquad (1)$$

where S_i is growing space area of a tree defined as a function of d.b.h. The rationale and derivation of S_i and $f(S_i)$ are as follows.

Figure 1 shows typical development of pure, even-aged stands of loblolly pine. These data are from a study of the effects of extreme density on stand growth (Harms and Langdon 1976). The figure shows quadratic mean stand diameters for ages 6 through 20 years plotted over surviving numbers of trees in stands having initial densities

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[1] Paper presented at the Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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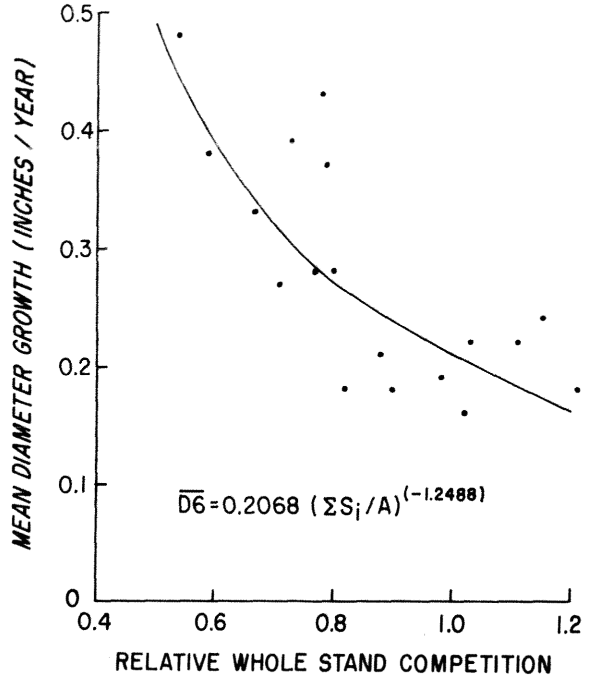

Figure 2.--Mean annual stand diameter growth of loblolly pine at age 14 in relation to stand level competition expressed in terms of the critical growing space, $\Sigma S_i/A$.

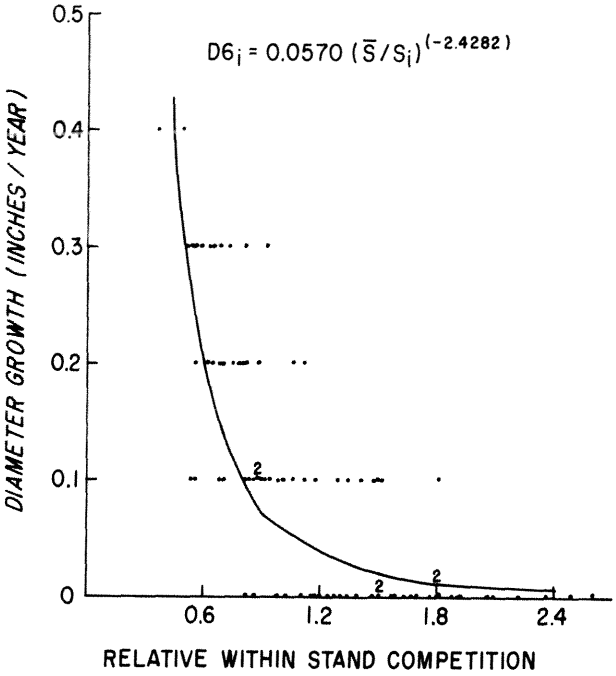

Figure 3.--Annual tree diameter growth of loblolly pine at age 18 in relation to within stand competition, $\bar{S}/S_i$.

The relationship of individual tree growth rate to the second component, $\bar{S}/S_i$, is shown in figure 3 for data from the 16,000-tree plots at age 18. A regression of the form

$$\text{Log}_{10}DG_i = b_0 + b_1\text{Log}_{10}(\bar{S}/S_i) \qquad (5)$$

where the variables are as defined above, was fit to the data. The regression was also significant at the 1% level and had an r^2 value of 0.57. The curve with its equation is shown in figure 3. There is a rapid decrease in diameter growth rate as the ratio, $\bar{S}/S_i$, increases to 1, which identifies the average critical growing space of the stand. At values greater than 1 growth becomes negligible as growing space decreases.

The form of the competition function is

$$f(S_i) = \left[1 + (\Sigma S_i/A)^{\phi_1}(\bar{S}/S_i)^{\phi_2}\right]^{-1} \qquad (6)$$

This particular form was suggested by Aikman and Watkinson (1980) and corresponds to the threshold response curves described by Thornley (1976). These are sigmoidal curves which describe plant growth responses to a critical growth factor. In the competition function, this growth factor is growing space, and the critical level is assumed to be the apparent critical growing space, S_i, per tree as defined by the self-thinning line.

The function approaches 1 as either of the competition terms approaches zero, indicating that there is little competition. It appraoches zero when $\Sigma S_i/A$ becomes 1 and $\bar{S}/S_i$ becomes large, indicating maximum competition for a tree in the lowest diameter class. The exponents ϕ_1 and ϕ_2 govern the severity of the effects of the two components on growth rate.

TEST RESULTS

The competition function was tested by fitting equation (1) to annual growth data taken from the stands in figure 1. The product of the apparent critical growing space, S_i, and the competition function, $f(S_i)$, is the independent variable and defines the effective or useable growing space of the individual tree. Separate regressions were fit to data from sets of plots having initial densities of 1000 and 16,000 trees per acre for stand ages 10, 12, 14, 16, and 18 years. The exponents of $f(S_i)$ were given the arbitrary values of 2 for ϕ_1 and 4 for ϕ_2. All regressions were statistically significant at the 1% level. Table 1 presents values of the regression and correlation coefficients.

Most of the intercepts had values near zero, and over half the slopes had values between 0.006 and 0.007. Differences among regressions, however, were significant. The correlation coefficients increased with age for both densities because the large variation in growth of young stands tended to decrease as the stands got older of 1000, 2000, 4000, 8000, and 16,000 trees per acre. The resulting curves show that as mean stand diameter increases with age, mortality induced by the intensifying competition for growing space gradually reduces the numbers of stems. At some point, depending on initial density, the relationship between mean d.b.h. and number of stems becomes linear on a log-log scale. The linear portion corresponds to the -3/2 power law proposed by Yoda and others (1963) to describe self-thinning populations of plants. The line is also equivalent to the stand density index relationship published by Reineke in 1933.

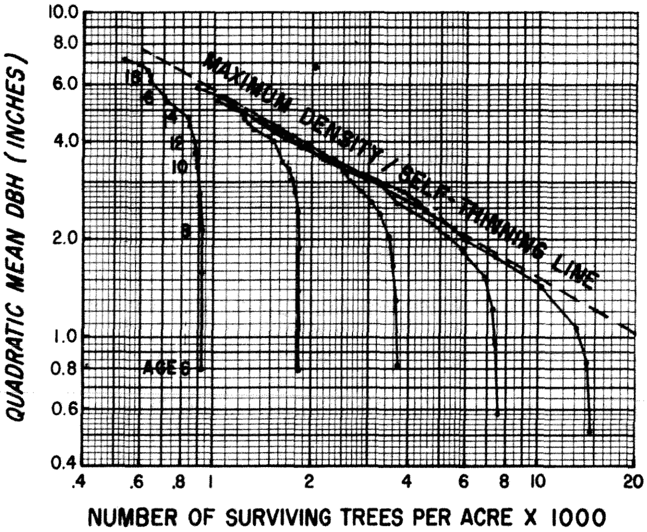

Figure 1.--Stand density-size relationships of self-thinning loblolly pine stands of initial densities of 1000, 2000, 4000, 8000, and 16,000 trees per acre for ages 6 through 21 years.

The self-thinning law implies that a plant of given weight or size requires a certain minimum growing space for its continued survival and development. As growing space falls below the minimum required, growth falls off and death eventually follows for some trees. The self-thinning line defines the apparent critical growing space S_i. The competition function is based on certain relationships that can be deduced from the self-thinning law.

For the loblolly pine data in figure 1, the self-thinning line can be described by the regression equation:

$$\text{Log}_{10}\overline{D} = 2.5277 - 0.5896\ \text{Log}_{10}(\rho) \qquad (2)$$

where $\overline{D}$ = quadratic mean d.b.h. and ρ = number of surviving trees per acre. The regression was fitted to data from plots having an initial density of 16,000 trees per acre and ages 10 thru 20 years. The mean apparent critical growing space, $\overline{S}$, is the reciprocal of the number of trees per unit area, ρ, and can be obtained by rearranging (2) so that

$$\text{Log}_{10}\overline{S} = (-4.2871 + 1.6960\ \text{Log}_{10}(\overline{D})) + \text{Log}_{10}43560 \qquad (3)$$

where $\overline{S}$ is in units of square feet. The apparent critical growing space, S_i, of any tree, i, can be calculated by substituting D_i for $\overline{D}$ in (3).

Summing the estimated S_i over all the trees in a stand of area, A, yields the minimum growing space needed by the stand, ΣS_i. Dividing ΣS_i by stand area gives a measure of occupancy (relative stand density), $\Sigma S_i/A$. This ratio is one component of the competition function and expresses competitive status or stress for the stand. The ratio will take values from near zero at low site occupancy to 1 or slightly above at full occupancy. As the ratio approaches 1, competition becomes increasingly severe until at a value of 1 the stand reaches the self-thinning condition of a fully occupied site as represented by the self-thinning line.

Even under conditions of maximum competition, not all trees in an even-aged stand are competing equally. Larger trees are known to have a competitive advantage over their smaller neighbors, especially those in the lower crown classes. Consequently, a second component is necessary to account for differences in competitive advantage for individual trees. A simple way to express the position of a tree in the stand is as a ratio, $\overline{S}/S_i$, of the average critical growing space of the stand to the critical growing space of an individual tree. The value of the ratio increases from less than 1 for larger than average growing space to greater than 1 as growing space falls below average.

The two ratios $\Sigma S_i/A$ and $\overline{S}/S_i$ comprise the competition function. Their relationship to diameter growth is shown in figures 2 and 3. In figure 2, mean stand diameter growth at 14 years taken from the data in figure 1, is plotted over the corresponding value of $\Sigma S_i/A$. A regression of the form

$$\text{Log}_{10}\overline{DG} = b_0 + b_1\ \text{Log}_{10}(\Sigma S_i/A) \qquad (4)$$

where $\overline{DG}$ and $\Sigma S_i/A$ are defined as above, was fit to the data. The regression was significant at the 1% level and had an r^2 value of 0.60. Figure 2 shows the curve and its equation in exponential form. It is apparent that $\Sigma S_i/A$ is associated with a curvilinear decrease in mean stand diameter growth rate as the ratio increases to 1, the condition of maximum competition.

Table 1.--Regression coefficients for the competition function as fitted to selected diameter growth data.

Initial stand density	Coefficients	Age 10	12	14	16	18
no./acre		years				
	b_0	0.1811	0.0932	0.2184	0.0607	0.0327
1,000	b_1	0.0070	0.0064	0.0070	0.0041	0.0057
	r^2	0.33	0.28	0.34	0.51	0.47
	b_0	0.0324	0.0264	0.0821	0.0222	0.0069
16,000	b_1	0.0076	0.0119	0.0099	0.0077	0.0071
	r^2	0.18	0.39	0.38	0.55	0.65

and within-stand competition became more uniform. An example of the relationship is shown in figure 4 for age 18 and an initial density of 16,000 trees per acre.

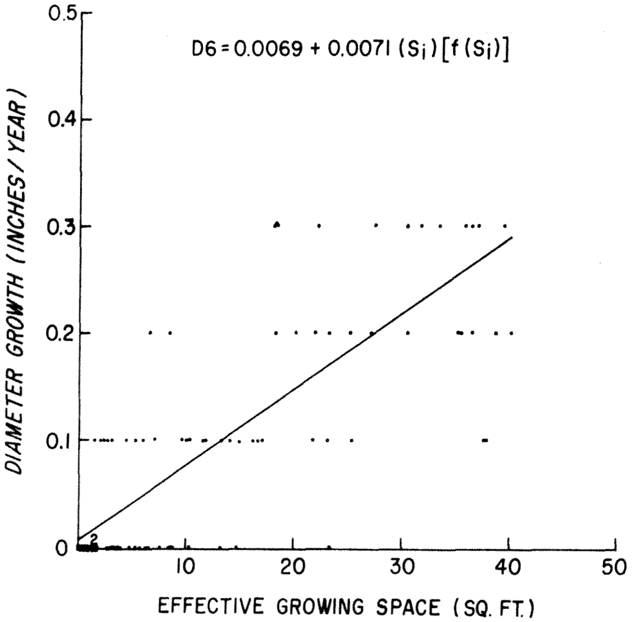

Figure 4.--Annual tree diameter growth of loblolly pine at age 18 in relation to effective growing space as estimated by the competition function, $f(S_i)$.

DISCUSSION

Only a few values for ϕ_1 and ϕ_2 have so far been tested. For ϕ_1, in addition to 2, 4 was used and the value for the exponent for the variable, $\Sigma S_i/A$, in the regression shown in figure 2 was tried. For ϕ_2, the values 4 and 8 were used. The value for the exponent for the variable $\bar{S}/S_i$, in the regression in figure 3 was also tried. The resulting regressions differed but little from those given in table 1.

In general, increasing the value of ϕ_1 will increase the severity of the restriction on growth caused by stand competition as ΣS_i approaches the area of the stand. Increasing the value of ϕ_2, on the other hand, increases the severity of competition from neighboring trees. As ϕ_2 becomes large, the competitive advantage of large trees over smaller ones increases rapidly. This feature of the function may permit adjustment or tuning of a growth model when its performance is being evaluated.

In its present form, the function operates at the stand level; it does not account for local competition experienced by a particular tree. Figures 3 and 4 show that there was considerable variation in the growth data used in the analysis. Trees of widely differing diameters often had the same growth rate. It is likely that local competition was responsible for some of this variation. Possibly, some form of competition index can be incorporated into the function, or perhaps the two terms can be modified to reflect more closely the growing space relationships of a subject tree and its competitors.

In conclusion, the preliminary tests of the function are encouraging. The two terms with their parameters may offer considerable flexibility in fitting it to different stages of stand growth and development. Further work is in progress.

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SITE AND STAND FACTORS AFFECTING
HEIGHT GROWTH CURVES OF LONGLEAF PINE PLANTATIONS[1]

William D. Boyer[2]

Abstract.--Some factors related to the form of height-over-age curves in longleaf pine plantations were identified from analyses of 660 periodically remeasured plots. Seventy percent of the variation among 32 plantations in form the growth curve was accounted for by stratifying planting sites into old fields, mechanically prepared and unprepared cut-over sites. Curve form was affected by site quality on prepared and unprepared sites, and by stand density on all sites.

INTRODUCTION

A major indicator of the productivity of southern pine plantations is site index at age 25 (SI_{25}), usually the mean height of dominant-codominant trees. Unfortunately, the early growth of southern pine plantations, including longleaf pine (Pinus palustris Mill.), is often so variable that use of a single set of site index curves has limited value at best and can be seriously misleading.

Often the predicted site index for a plantation changes over the years, whatever curves are used. Errors multiply as the time from index age increases (McGee and Clutter 1967). Even small errors in site-index estimates can cause large miscalculations of expected volume growth. For example, a change from 60 to 55 ft in SI_{25} reduces the projected cu-ft volume yield of a slash pine plantation at age 20 by 25 percent (Bennett et al. 1959).

Past studies suggest that height-over-age curves for southern pines established on old fields may differ not only between plantation and natural stand but also from similar stands established on cutover forest sites (Chapman 1938, Allen 1955, Bailey et al. 1973). Form of height-over-age curves may also be affected by other stand and site variables, particularly stand density (Bennett 1975, McClurkin 1976) and site quality (Beck and Trousdell 1973, Graney and Burkhart 1973).

For this study, height-over-age data from 660 remeasured plots, primarily the longleaf pine phase of the Southwide Pine Seed Source Study (SPSSS), were used to investigate how site and stand conditions affect early height growth of longleaf pine plantations.

METHODS

The SPSSS provided data from 637 of 660 remeasured plots in this study. The other 23 plots were from two separate studies in west Florida. Trees on all plots were scheduled for measurement at age 3 and 5, and at 5-year intervals thereafter although the remeasurement schedule was not always strictly met. Some plots (136) were last measured at age 20, 21, or 22. The rest were last measured at age 15 except for 67 plots last measured at age 16 or 17. In all, there were 2737 height-over-age observations.

SPSSS series 1 and 2 (planted during winter 1952-53) and series 4, 5, and 6 (planted during winter 1956-57) were represented in this study, with 34 plantings in coastal states from Texas to North Carolina. Plantings were replicated at two locations. Also, replicates were combined, making a total of 32 recognized planting locations. The parent study is described by Wells and Wakeley (1970).

At each examination, number of surviving trees and height of each survivor were recorded for individual plots. The mean height of the tallest half of surviving trees on each plot was determined and represented the dominant-codominant fraction of the stand.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

[2] The author is Principal Silviculturist at the George W. Andrews Forestry Sciences Laboratory, Auburn, AL, maintained by the Southern Forest Experiment Station, Forest Service--USDA, in cooperation with Auburn University.

All plantations were classified into three groups according to planting-site condition: Old fields (283 plots and 1172 observations), mechanically prepared cutover forest sites (116 plots and 448 observations) and unprepared cutover forest sites (261 plots and 1077 observations). All observations combined were given a stepwise regression analysis of the form:

$$\text{Log}_{10}\ \text{Height} = b_o + b_1\ (\text{Age})^{-1/2} + b_2\ (\text{Age})^{-1} + b_3\ (\text{Age})^{-2} + b_4\ (\text{Age})^{-3} + b_5\ (\text{Age})^{-4}.$$

The analysis determined which of the included independent variables would give the best single-variable regression.

The single variable regression model considered the best was fitted to the height-over-age observations for each individual plot, resulting in 660 equations. Further analyses explored the relationship of slope coefficients for individual plots, as a dependent variable, to recorded site and stand variables. These were primarily stand density (surviving trees per acre at age 10), site quality (height of tallest half of trees per plot at age 15), and the three planting-site conditions.

Coefficients for all 136 plots through age 20-22 were compared with coefficients derived from the same plots through age 15 only. Values of slope coefficients from plots through age 20-22 differed from age-15 values by an average of only 0.7 percent. Plantation height-growth patterns in this study appeared to be well established by age 15, so all slope coefficients were pooled for analyses without regard to plantation age at last measurement.

RESULTS

The best single variable regression for all 2737 height-over-age observations was: $\text{Log}_{10}\ \text{HT} = 1.8844 - 6.1764\ (\text{Age})^{-1}$. The coefficient of determination (r^2) was 0.8484. The only other variable contributing significantly (.05 level) to the regression was $(\text{Age})^{-4}$, which, when included in the equation, resulted in an R^2 of 0.8497.

The model $\text{Log}_{10}\ \text{HT} = b_o + b_1\ (\text{Age})^{-1}$ was fitted to each individual plot: 520 (79 percent) of the resulting equations had r^2 values of 0.99 or better. Slope coefficients (b_1), with negative sign omitted, became the dependent variable in analyses of the relationship of planting-site condition, stand density, and site quality to the form of early plantation height growth.

Planting-to-planting and plot-to-plot variation in slope coefficients was high. Classification of the 32 SPSSS plantation locations into the three planting-site conditions accounted for 70 percent of the variation among plantings in average slope coefficient. The mean, standard deviation, and range of coefficient values for the 32 plantation locations are illustrated in figure 1 for each planting-site condition. Much of the remaining variation can probably be attributed to factors such as two different years of plantation establishment, varying sets of seed sources, and geographic location with its associated climatic and soil-site conditions.

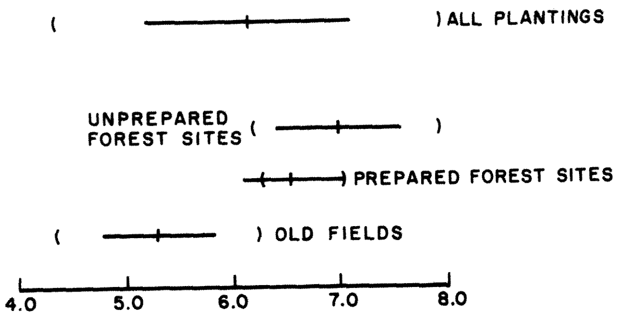

Figure 1.--Mean, standard deviation, and range of growth curve coefficients for plantings on old fields, prepared and unprepared forest sites, and all plantings combined.

Both stand density and site quality had a small but highly significant effect on growth curve coefficients. Classification into the three planting-site conditions alone accounted for 43 percent of plot-to-plot variation. Addition of stand density raised this value to 47 percent and site quality to 48 percent. Stand density affected growth curve form in each of the three planting site conditions. Site quality affected curve form only on prepared and unprepared sites, indicating that site index curves for these conditions will be polymorphic.

Planting-site condition had the greatest impact on curve form, with the largest contrast being between old fields and unprepared forest sites. The difference, for plantings with a stand density of 700 trees per acre, is illustrated in figure 2 for four site index (SI_{25}) classes. For SI_{25} of 60 ft, 10-year-old plantations on old fields are about 5 ft taller than similar plantings on unprepared forest sites. The comparatively rapid early growth on old fields can be attributed to less low competition than on unprepared cutover sites. Competition was primarily from shrubs and herbaceous vegetation because residual trees had been removed or killed in all plantations. The extreme of growth curve differences among individual plots is shown in figure 3. With a common SI_{25} of 50 ft, the difference in tree height at age 10 is 20 ft. The upper curve is an old field plot, the lower curve an unprepared forest plot. The regression r^2 values for each of these two plots were 0.999 and 0.994, respectively.

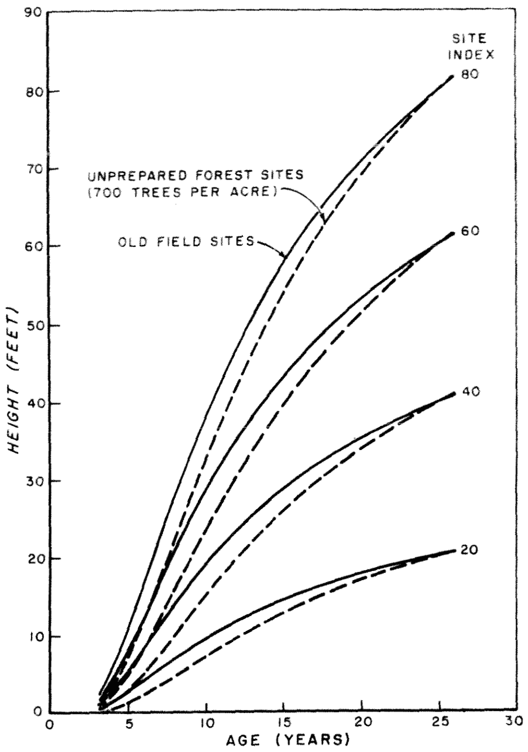

Figure 2.--Comparison of growth curves on unprepared forest sites with those on old fields for selected age 25 site index values.

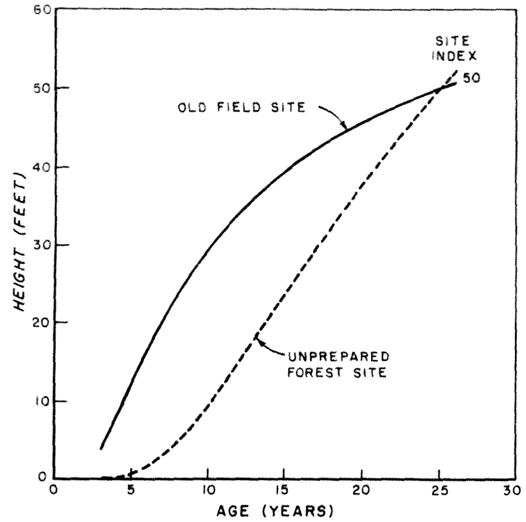

Figure 3.--Comparison of growth curves on two plots with greatest observed difference. Upper curve-old field; lower curve-unprepared forest site.

Differences in growth curves between prepared and unprepared forest sites are not as great as those between old fields and unprepared sites (fig. 4). For SI$_{25}$ of 60, 10-year-old trees on prepared sites have about a 3 ft height advantage over similar plantings on unprepared sites.

Growth curves for prepared forest sites were close to those of old fields on good sites, but differences increase as site quality declines (fig. 5). For SI$_{25}$ of 80, there was no apparent difference in the curves, but for SI$_{25}$ of 40, old field plantings at age 10 had about a 2 ft advantage over prepared site plantings. As noted earlier, site quality affected curve form on prepared sites, but not old fields, hence the opportunity to converge. On good sites, intensive mechanical site preparation resulted in growth equivalent to that expected on old fields. Even on poor sites, differences were relatively small.

The observed effect of stand density on curve form is illustrated in figure 6 for an old-field site, one with 250 and the other with 1200 trees per acre. Given the same SI$_{25}$, the curve for the high density stand is higher than that for the low density stand. The difference is not great, amounting to slightly over 2 ft at age 10 for SI$_{25}$ of 60 ft. In this illustration, SI$_{25}$ was set at an equal value for comparison of growth curves for each of the two stand densities. Early plantation growth for both densities on an equivalent site should be identical until canopies close. Afterwards height growth for the high density stand can be expected to fall below that of the low density stand.

CONCLUSIONS

Results of this study indicate that form of height-over-age curves are influenced by planting-site variables and stand density. The degree of intensity of preplanting site preparation apparently has the greatest impact on form of the height-over-age curves. It must be considered when attempting to estimate site quality from early plantation height growth. Site quality per se affected curve form on both prepared and unprepared forest sites, suggesting that site index curves developed for these two conditions will be polymorphic. The stand density effect was highly significant but small. So within the range of densities expected in most plantations, it will have a negligible effect and can be reasonably ignored.

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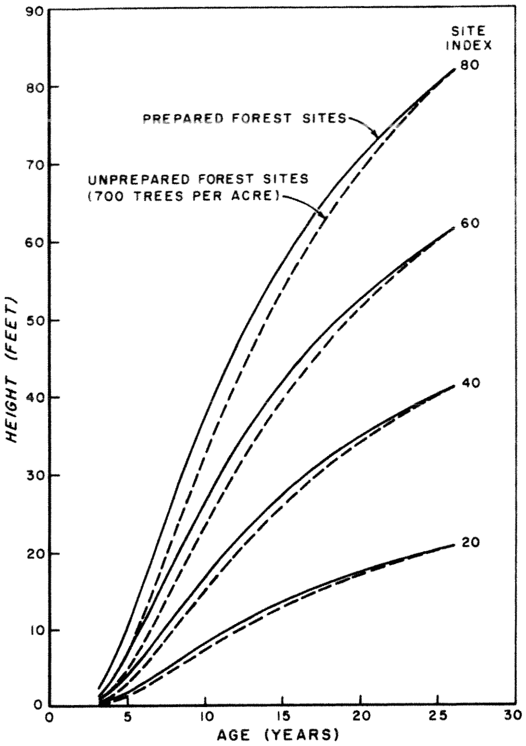

Figure 4.--Comparison of growth curves on unprepared forest sites with those on mechanically prepared sites for selected age 25 site index values.

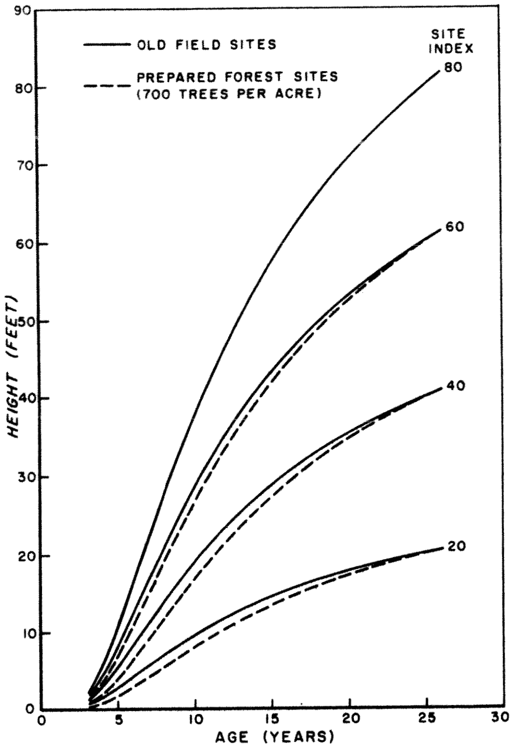

Figure 5.--Comparison of growth curves on mechanically prepared sites with those on old fields for selected age 25 site index values.

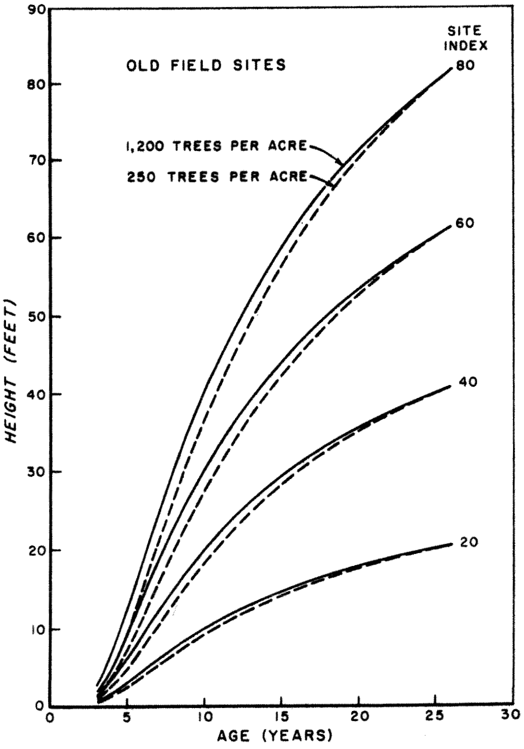

Figure 6.--Comparison of old field curves for plantings having 250 trees per acre, at age 10, with those having 1200 trees per acre.

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SEEDLING SURVIVAL ESTIMATES USING 35MM AERIAL PHOTOGRAPHY:

A NEW APPROACH[1]

Craig D. Campbell
and
Roy A. Mead[2]

Abstract.-- Seedling survival inventories for loblolly pine (Pinus taeda L.) plantations in eastern Virginia were performed by using small format, 35mm, color infrared aerial photography. The test sites selected were (1) chopped and burned or (2) K-G bladed, windrowed, and bedded. One year old plantations representative of both site preparation methods were tested. The photography was obtained during the winter of 1980 at several scales. Survival counts were made from the photos and compared with the counts made on the ground. Economic and accuracy comparisions were made between the photo and current industry field methods.

INTRODUCTION

The costs of regenerating the southern pines are increasing rapidly. As natural stands are harvested, they are being replaced by pine plantations. The livelihood of the forest industry in the Southeast depends on the successful regeneration of these plantations. To ensure their success, we protect this capital investment with intensive site preparation in an effort to control competing vegetation. Due to the size of this investment, most companies require that seedling survival estimates be made at the end of the first growing season. The purpose of this paper is to outline a proposed photogrammetric method for estimating seedling survival and compare it with the current methods used by the forest industry.

PHOTOGRAMMETRIC METHOD

There are several recent papers on photogrammetric procedures to estimate seedling survival (Nelson, 1977a and Schaefer, 1978). However, none of these incorporate the use of 35mm aerial photography, nor do they present an operational system to use with a photogrammetric procedure. One or more of the following points were found to be deficient in the papers reviewed: (1) the costs for the ground surveys, (2) the sampling intensity of the ground survey, (3) the costs for the photogrammetric survey, and (4) the amount of photo coverage obtained by the photogrammetric survey (Grumstrup and Meyer, 1977; Nelson, 1977a; and Schaefer, 1978). This section presents a proposed operational photogrammetric method and the experimental procedure which supports it.

Procedure

The experimental procedure for aerial photo acquisition involves the use of Kodak 35mm color infrared (CIR) ektachrome in conjunction with a 35mm SLR camera with a 205mm telephoto lens. The color shifting properties of the CIR film allow for better species discrimination and ease of interpretation over standard panchromatic and color films (Howland, 1980). A 205mm telephoto lens was chosen to minimize displacement while allowing for safe flying heights at the scales of interest. This procedure was used in an attempt to image 1-0 loblolly pine (Pinus taeda L.) seedlings after one growing season on intensively prepared sites. The aerial photography was taken during March of 1980 because the maximum contrast between the annual and deciduous vegetation and the evergreen vegetation exists during the winter months. The photography was obtained using the above system and a helicopter platform.[3] The

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[1] Paper presented at the Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

[2] The authors are Graduate Research Assistant and Assistant Professor, respectively, in the School of Forestry and Wildlife Resources, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061.

scales of photography were 1:300, 1:600, 1:740, 1:890, and 1:1040. On the plantations investigated,4/ at a scale of 1:300, 93 to 100 percent of all seedlings were imaged on the film. On the same sites, at a scale of 1:890, 84 to 90 percent of all seedlings were imaged on the film. Due to the ability to image one year old loblolly pine seedlings with this procedure, an operational photogrammetric method using the procedure was designed.

Proposed Method

The proposed operational method depends on the integrated use of a 35 mm aerial photo system. Initial small scale vertical photography would be flown and the photo detail transferred to a base map (e.g. U.S.G.S. quadrangles) to determine the number of hectares for planting or site preparation payments. Standard transect lines and plots are then located for a given sampling intensity and their coordinate positions are recorded.5/ The transects are then flown with large scale, vertical, aerial photography (i.e. the photography described) and the seedling counts are made directly from the slide projections. The counts can be corrected to per hectare figures of seedling survival based on the apriori knowledge of the sample point coordinates, the flying height of the aircraft, the camera system, and the initial number of trees planted per hectare. Using this information, the required calculations and actual mapping of seedling survival for each plantation can be done by simple computer packages. The end product is a contour map of survival percentages or numbers of trees per hectare for every plantation inventoried and a permanent film record of that inventory.

INDUSTRY METHODS

The current methods for estimating seedling survival involve the use of fixed area plots that range in size from 4.05 to 40.5 square meters. Depending on the area, the survival plots are allocated on a two to five plot per hectare basis with predetermined transects. However, industry cruises range from 0.05 to 2.0 percent and yield survival data which is referenced for each plantation in a coordinate or grid system. From the field data, the surviving number of trees per hectare are calculated and compared with the number of trees planted per hectare. The resulting survival percentages are transferred to a base map and areas of unacceptable regeneration are manually located. The disadvantage of these methods is that they require a relatively large number of man-hours (Nelson, 1977b).

RESULTS AND DISCUSSION

As previously stated, the objective of this paper is to compare and contrast the proposed photogrammetric survey with the current surveys used by the forest industry in the Southeast. It is proposed that the photogrammetric survey would take less time to complete than the same survey would on the ground. From information provided by industry cooperators6/, initial comparisons between the two methods are possible. A summary of their respective advantages and disadvantages follows.

The ground survey is the primary method used by the forest industry to evaluate seedling survival. The inventory methodology is simple, requiring only the enumeration of seedlings within a plot boundary. The industry survey also provides an opportunity for an on-site inspection of the quality of the planting and the general condition of the plantation. A major concern is the quality of this survey with respect to the investment it represents. Generally, the sampling intensity is very small and the plot locations are subject to bias or error.

The photogrammetric survey is also subject to several problems. The use of CIR film limits the time of day during which the photos can be taken because shadows (e.g. from low sun angles) on CIR film are completely black. Due to the oblique nature of the photography, competing vegetation (e.g., stump sprouts, sedges, and other annuals) caused problems by casting shadows on seedlings and by reducing the light reflected by the seedlings. The relative size or height of individual seedlings and/or their vigor (i.e. amount and color of foliage) were other problems with interpreting the imagery. The smaller or

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3/Earlier flights proved the fixed-wing planes to be unsatisfactory for covering the established research plots due to inadequate flight line control and tip. Due to the lack of a helicopter mount these photos are low oblique exposures.

4/Two site preparations were investigated: (a) A drum-chopped and burned plantation owned by the Chesapeake Corporation and (b) a windrowed and bedded plantation owned by the Union Camp Corp. (Franklin, Va.).

5/ The x and y coordinates are needed to locate the sample point within the plantation and the z coordinate or elevation of the point is needed to calculate the sample size.

6/The Chesapeake Corp., West Point, Va. and the Union Camp Corp., Franklin, Va. were willing and helpful cooperators and we extend them our gratitude.

less vigorous seedlings were often not interpreted. These problems accounted for all seedlings that were not imaged. It was found that the photo interpretation improved significantly (Bishop *et al*., 1975)7/ as the angle from the vertical was reduced. In other words, the closer the seedlings were to the nadir the better the interpretation. The remaining problem is one of misclassification of vegetation. Due to the design of the sample, no previous imagery of similar sites was available for training the photo interpreter. This often led to the classification of American Holly (*Ilex opaca* Ait.) as seedlings. In fact, they have quite different spectral signatures. Therefore an experienced photo interpreter could differentiate between the holly and the seedlings. Most of the problems associated with this method deal either with the non-vertical nature of the photography or the lack of training sets for the interpreter.

There are several advantages in using the photogrammetric method. Stand areas can be checked without ground surveys. The plantations need only be visited if the success of the plantation is in question. The aerial survey also allows for inspection of the quality of the planting and the general condition of the plantation. The aerial survey allows for increased sampling intensity over the ground surveys. This can range from two to forty times the intensity of current industry surveys. All manual work required to manipulate the cruise data can be done by computer and in less time. The final products not only tell which plantations have survival problems but where those problems are located within the plantation. The last advantage of the photogrammetric method is that it requires less time to complete than a comparable ground method.

The time and cost comparison of these methods is best illustrated by example (fig. 1). In working with the initial data, the aerial survey can be completed in one-third the time it takes two men to complete the same ground survey. However, the photo method costs more than the ground method (fig. 1).8/ The decision to use the photo method should be made by considering their relative sample intensities. If the photo sample intensity is twice that of the ground sample

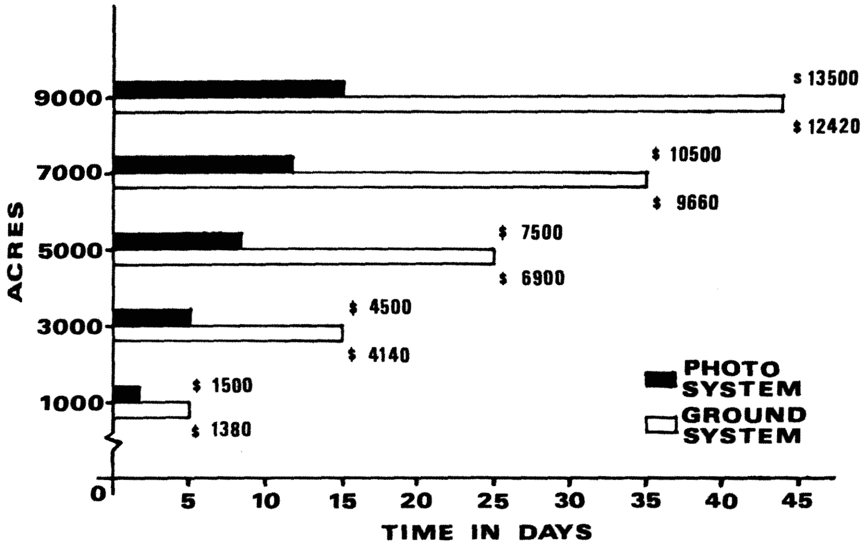

Figure 1.--Time and costs required to complete both the photogrammetric and ground surveys given the total number of acres inventoried.

7/ Statistically tested by using discrete multivariate analysis at the 95% confidence level.

8/The aerial survey includes film costs and developing, one man on full time (8 hrs/day), and the rental of a helicopter and pilot at $150/hr. for 4 hrs./day. The ground survey includes travel costs and two men on full-time (8 hrs/day).

intensity, the cost per unit of sample intensity (percent sample) for the photo method is approximately 54 percent of that for the ground method. Helicopter rental is the largest factor affecting the absolute cost of the photo method. However, the use of leasing plans or company ownership could easily reduce the absolute cost of the survey to less than that of the ground methods.

CONCLUSIONS

While there exist several problems with the photogrammetric method proposed in this paper, most of them can be solved with true vertical photography and a trained photo interpreter. The photo system is further justified by additional uses such as area determinations and other inventories. Also the photo method requires less time to complete the same inventory. The sampling intensity of the photo method may be two to forty times that of the current industry methods which in turn reduces the cost per unit of sample intensity. The end products for the photo inventory are more easily produced than by conventional surveys and the photos are a permanent record for each plantation. In this study, the absolute costs for the photo method are greater due to the cost of helicopter rental. However, reduction of this cost would reduce the absolute cost of the photo method so as to make it financially competitive with the ground method.

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COLOR AERIAL PHOTOGRAPHY AS A GUIDE TO FOLIAR NUTRIENT LEVELS AND SITE INDEX IN LOBLOLLY PINE PLANTATIONS[1/]

Al Lyons and Edward Buckner[2/]

Abstract. -- Color aerial photographs were obtained during the winter of 1979-80 of extensive areas of loblolly pine plantations in Franklin County, Alabama, and Wayne County, Tennessee. Photo interpreters identified 3 Munsell color classes that would accommodate the range of colors detected in loblolly pine plantations on these photographs. Each of these colors reflected a specific foliar nitrogen and site index range.

This technique permitted evaluation of productivity (site index) and foliar nutrient status from color aerial photographs, enabling more efficient land classification and possibly more efficient use of fertilizers for increasing productivity.

INTRODUCTION

The rapid expansion that has characterized the forest products industry in the South over the last decade has greatly increased the demand for roundwood, especially pine. To satisfy this demand, forest product industries are intensifying efforts to increase forest productivity on present ownerships rather than incur the high acquisition and maintenance costs of expanding their forest landownership. Fertilization provides one means of accomplishing this goal where suitable sites can be identified. Wide variations in response have demonstrated that care must be exercised in selecting plantations that will respond to increased nutrient levels.

Adequate foliar nutrient levels, especially N, usually result in dark-green foliage, the result of high chlorophyl concentrations. Chlorosis (yellowing) is commonly related to low foliar nitrogen levels (Pritchett, 1979).

Winter yellowing of loblolly pine (_Pinus taeda_ L.) foliage, a common phenomenon throughout much of the South, has been related to foliar nutrient levels, especially N and P. Blinn (1978) color coded loblolly pine foliage to one of six discrete Munsell color signatures. As foliage color changed from yellow to dark-green there was a stepwise increase (highly significant increase) in both N and P. While positive correlations were found with both elements, the nitrogen relationship appeared most discrete. These high correlations between foliage color and nutrient concentrations suggest that color aerial photographs might be useful for determining foliar nutrient levels within and among loblolly pine plantations.

EXPERIMENTAL PROCEDURE

During the winter of 1979-80 color aerial photographs (0.4 um - 0.7 um) were obtained of loblolly pine plantations in Franklin County, Alabama, and Wayne County, Tennessee. Photographs were taken at 5,000, 10,000, and 15,000 feet using a Wild RC-10 camera mounted in a Cessna 411 Aircraft. Kodak Aerocolor Negative film 2445 (ester base) was used.

Rigid control over processing assured uniform color renditions on the various photographs. Three separate interpreters using acetate overlays drew boundaries between color classes that could be detected within loblolly pine plantations as seen on the color aerial photographs. These color units were then coded to a specific Munsell color chip.

[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980. Research funded by Champion Timberlands, Champion International Corporation.

[2/] The authors are, respectively, Graduate Research Assistant and Associate Professor, Department of Forestry, Wildlife and Fisheries, The University of Tennessee, Knoxville, TN 37901.

Ground truth was established by taking 3 plots in each color unit identified in a plantation. At each sample plot, foliage was collected from 4 trees and composited to make one sample. Soil samples were collected near each sample tree and composited to make one soil sample. Additional data collected from each plot included (site index, basal area, average diameter growth over last 5 years, aspect, and percent of slope).

Foliage samples were oven-dried at 70 degrees C and ground in a Wiley mill to pass a 20-mesh screen. Nitrogen was determined by the Kjeldahl Method using a Tector distilling unit and titrator. P was determined colormetrically, while K, Ca, and Mg were determined by atomic absorption spectrometry. Soil P and K and soil Ph were determined at the Tennessee Agricultural Extension Service Soil Testing Laboratory.

RESULTS

Photo interpreters were able to identify 3 distinct color units in loblolly pine plantations: green (2.5 G 3/4), yellow-green (2.5 GY 5/4), and yellow (2.5 GY 6/6). Although color shifts could be detected in plantations at all 3 altitudes, the 5,000-foot photographs provided the best resolution.

Foliar analysis revealed a significant relationship (.05 level) between foliar nitrogen levels and aerial photo color units (Figure 1) in which foliar nitrogen in green areas averaged 1.58 percent, yellow-green areas averaged 1.33 percent and yellow areas averaged 1.20 percent. Foliar P in green areas was significantly higher (.05 level) than in the yellow-green and yellow areas; however, there was no significant difference on the yellow side of the color range (Figure 2). No significant correlations were found between foliar K, Ca, and Mg and color units in loblolly pine plantations on these aerial photographs.

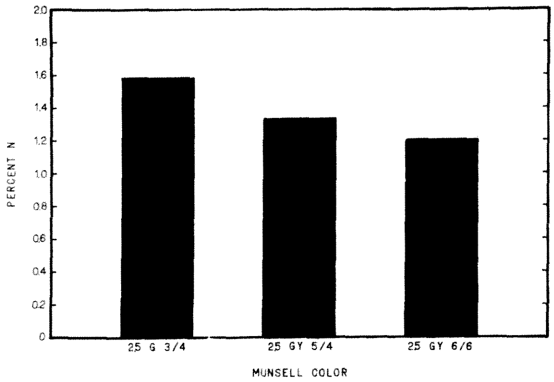

Figure 1.--The relationship between foliar N and crown color determined from color aerial photographs.

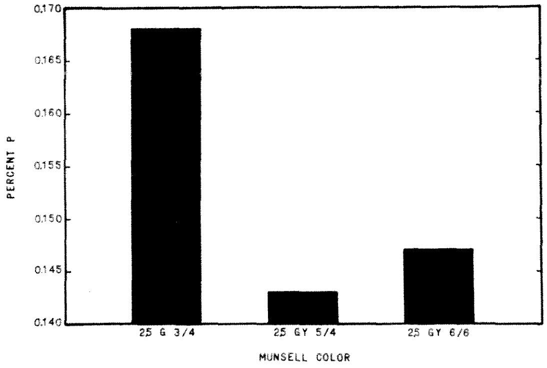

Figure 2.--The relationship between foliar P and crown color determined from color aerial photographs.

Soil analysis revealed a drop in P (Figure 3) and K (Figure 4) from green to yellow; however, only the decrease in soil P from yellow-green to yellow was statistically significant (.05 level).

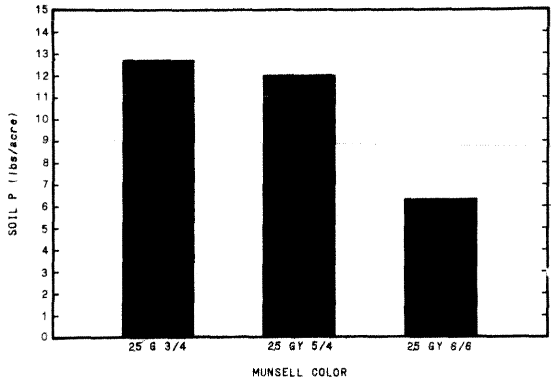

Figure 3.--The relationship between soil P and crown color determined from color aerial photographs.

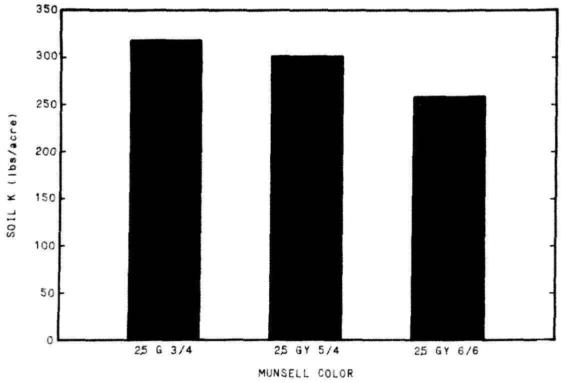

Figure 4.--The relationship between soil K and crown color determined from color aerial photographs.

Site index for loblolly pine ranged from a high of 100 (base 50) in the green areas to a low of 40 in the yellow areas. Average site indices for the 3 color units are: 90 for the green areas, 81 for the yellow-green areas, and 68 for the yellow areas (Figure 5). Stand basal areas decreased from 137 square feet per acre in green areas to 67 square feet per acre in yellow areas (Figure 6).

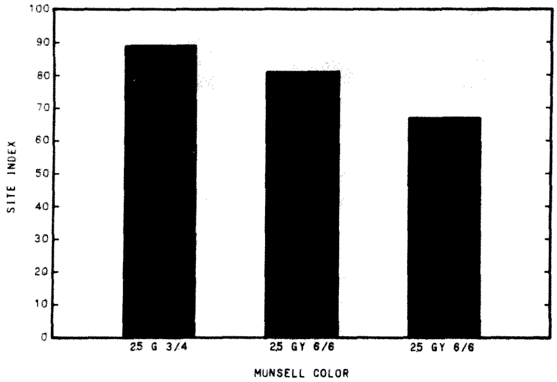

Figure 5.--The relationship between site index and crown color determined from color aerial photographs.

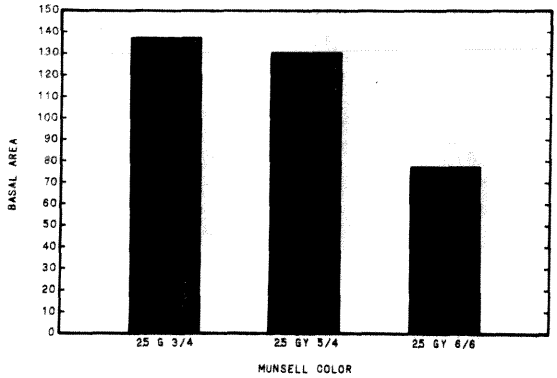

Figure 6.--The relationship between basal area and crown color determined from color aerial photographs.

DISCUSSION

Resource managers generally feel that research is needed to develop low cost applications of aerial photography to reduce expensive field measurements (Mead, 1980). The procedure described permitted the effective subdivision of loblolly pine plantations into categories based on: (1) nutrient levels, (2) site index, and (3) basal area.

Detection of foliar color units is possible from 10,000 feet (ratio 1:20,000) and 15,000 (1:30,000) provided visibility is approximately 40 miles. The use of 5,000-foot photography (ratio 1:10,000) reported here provided the most definitive results and photographs can be taken with visibility as low as 10 miles. Winter yellowing in loblolly pine generally occurs between December 1 and March 1; aerial photography for determining nutrient status should be restricted to this period. Photographs should be taken between 10:00 A.M. and 2:00 P.M. to minimize shadow effects, a serious problem in hilly terrain.

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FERTILIZER RESPONSE AND BIOMASS ACCUMULATION OF A 5-YEAR-OLD SWEETGUM PLANTATION[1]

Timothy T. Ku, John K. Francis, and Charles R. Blinn[2]

Abstract.--A sweetgum plantation was established in 1975 to evaluate the effects of N, P fertilizers on growth and biomass accumulation. Positive response to the N and, to a lesser degree, the N + P treatment were noted the first year after fertilization. At age 5, total biomass averaged 2.5 T/ha: 25% leaves, 25% branches and 49% stems. Biomass accumulation was 50% greater on N treated plots than control.

INTRODUCTION

Earlier trends and projections from wood using industries indicated an increasing demand for hardwoods in the South. Hardwood plantations have been established in recent years to meet such demand by Corporations mainly in the fertile alluvial valley of the Mississippi River. Since land clearing for farming has been proceeding steadily, the best sites available for hardwood timber production has diminished in the area. It is necessary, therefore, to turn to other sites for possible hardwood production.

In 1974, a cooperative study between the Department of Forestry, University of Arkansas at Monticello and USDA-Forest Service was initiated to evaluate the potential production of hardwoods on a moderately poor silty upland site, a part of the University Experiment Forest. Sweetgum (Liquidambar styraciflua L.) was selected since it is one of the endemic hardwoods and a desirable species for both pulping and solid wood uses. Because of the inherent slow growth of the sweetgum coupled with the low fertility of the soil, the objective of the study was to evaluate the effects of fertilizers on growth, nutrient accumulation and biomass production of planted sweetgum on a marginal hardwood site. This paper will not report the nutrient status since chemical analyses are incomplete.

METHODS

An old field of poorly-drained Henry silt loam, a coarse-silty, mixed, thermic, Typic Fragi aqualf was cleared of heavy brush and disked three times in late 1974. One-year-old sweetgum seedlings from an Arkansas source were hand-planted in February 1975, at 2.75 M x 2.75 M spacing. Fifty seedlings in 10 rows of 5 trees each were planted in each plot. The interior 24 trees were used as measurement trees to evaluate growth and stand development.

The statistical design was 6 randomized blocks of 4 fertilizer treatments: N, P, N + P and Control. Fertilizers were applied by a tractor drawn 4-foot-wide spreader in March, 1979 (at plantation age 4) at the rates of 280 Kg N, 168 Kg P, 280 Kg N + 168 Kg P per ha. No fertilizer was added on control plots.

Machine cultivation was maintained during the first two growing seasons to control competing vegetation. Survival of the planted seedlings was 81% at the end of the first growing season and they averaged 42 cm in total height.

Since 1977, the following measurements were taken: total height, diameter at 30 cm above ground, crown length and crown width. Beginning with the 1979 measurement, additional diameter at breast height measurement was taken when trees averaged more than 3 meters in height

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

[2] Timothy T. Ku is professor, Department of Forestry, Agricultural Experiment Station, University of Arkansas at Monticello. John K. Francis is Soil Scientist at the Southern Hardwoods Laboratory, which is maintained at Stoneville, Mississippi, by the Southern Forest Experiment Station, Forest Service--USDA, in cooperation with the Mississippi Agricultural and Forestry Experiment Station and the Southern Hardwood Forest Research Group. Charles R. Blinn was Research Assistant, Department of Forestry, University of Arkansas at Monticello, is now Research Assistant, College of Forestry, University of Minnesota, St. Paul.

In October 1977, one sample tree from each plot using the mean tree technique,[3] (a total of 24 trees) was harvested by shearing at the ground level for biomass and nutrient analysis. Each tree was separated into the following components: leaves, current branches, old branchwood, old branchbark, stemwood, and stembark. Components were weighed fresh and again after oven-drying at 70°C.

In October 1979, one growing season after fertilizer treatment, 6 trees from each treatment (one tree from each plot) covering entire ranges of height and diameter (dbh) were harvested. The change of population sampling technique was necessary to accommodate a greater range of tree sizes resulting from advanced stand development and crown differentiation.

RESULTS AND DISCUSSION

Fertilizer Response

Average values in height, diameter at 30 cm above ground, crown length and crown width for two years prior to fertilization (1977, 1978) and one year after fertilization (1979) are presented in Table 1. The sweetgum grew slowly at first. For the last year before fertilizer treatment (1978), the annual increments were: 92 cm in height, 1.1 cm in diameter at 30 cm above ground, 96 cm in crown length and 27 cm in crown width. It appeared that none of the average values of the intended treatment plots were significantly different prior to fertilizer treatment.

Measurements in 1979, one growing season after fertilizer treatment, showed that N and N + P plots made significantly more growth than Control or P only plots. On the average, treatments containing N increased height growth by nearly 30%, diameter growth by 25%, crown length by 20% and crown width by 61% (Table 2).

Biomass Accumulation

From the 1979 harvest, linear regression equations were derived from dry weights of felled trees in each treatment to estimate biomass accumulation for that treatment. The regression equations followed the general form:

$$W = A + B\,(D^2H)$$

where W is the predicted biomass dry weight of individual tree, grams.
D is the dbh of the tree, mm.
H is the total height of the tree, cm.
A and B are the intercept and slope of the regression line.

Table 1.--A comparison of average height, diameter, crown length and crown width between fertilizer treatments.

Treatment	Height			Diameter at 30 cm			Crown length			Crown width		
	cm											
	'77	'78	'79	'77	'78	'79	'77	'78	'79	'77	'78	'79
N	163	259	353*	2.2	3.3	5.1**	135	233	318**	83	113	150*
P	162	257	329	2.2	3.4	4.8	135	235	292	83	111	138
N+P	159	245	341	2.0	3.0	4.7	132	220	299	77	100	137
C	155	247	321	2.0	3.2	4.6	123	219	287	81	107	130
Mean	160	252	336	2.1	3.2	4.8	131	227	299	81	108	139

** $P < 0.01$
* $P < 0.05$

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[3] Crow, T. R. 1971. Estimation of biomass in an even-aged stand--regression and "mean tree" techniques. in Forest Biomass Studies, XVth IUFRO Congress, University of Maine. pp 35-48.

Table 2.--First Year Growth Response to Fertilizer Treatments.

Treatment	Height		Diameter at 30 cm		Crown length		Crown width	
	cm	%	cm	%	cm	%	cm	%
N	94*	27	1.8**	29	85*	24	37**	61
P	72	--	1.4	--	57	--	27	17
N+P	96*	30	1.7	21	79	16	37**	61
C	74		1.4		68		23	

** $P < 0.01$
* $P < 0.05$

Table 3.--Parameters of Biomass Prediction Equation by Fertilizer Treatments-1979 Harvest.

Treatments	Intercept (A)	Slope (B)	r^2
N	505.3266	.5629	.90
P	734.3317	.5202	.81
N+P	121.1416	.6913	.99
C	611.4199	.4577	.85

Table 4.--First Year Response of Biomass Accumulation by Fertilizer Treatments.

Treatment	Biomass 1977		Biomass 1979		Periodic Increment		Periodic Annual Increment
	T/ha	%	T/ha	%	T/ha	%	T/ha
N	0.461	33	2.976*	48	2.515*	51	1.258*
P	0.496	43	2.688	34	2.192	32	1.096
N+P	0.424	22	2.513	25	2.089	26	1.045
C	0.346	--	2.007	--	1.661	--	0.830
Mean	0.432		2.546		2.114		1.057

*$P < 0.05$

From the regression equation constants presented in Table 3, biomass of each tree was calculated and summarized in Table 4.

Results from biomass sampling of 24 trees harvested in 1977 indicated these 3-year-old sweetgums have accumulated 0.432 T/ha of biomass (Table 4) with the following distribution of tree components: leaves 35%, branches 23% and stems 42% (Table 5).

On the biomass distribution of tree components as trees develop and age, there is apparently a shift toward greater accumulation in stems (Table 5). Foliage diminished from 35% of the total biomass at age 3 to only 25% at age 5, an indication of increased photosynthetic efficiency with a greater accumulation of usable biomass in woody stems.

At age 5, biomass accumulation was 3 T/ha in N plots, 50% greater than the 2 T/ha accumulated in control plots. The periodic increment between age 3 and 5 was 1.26 T/ha/yr for the N plots and 0.83 T/ha/yr for the control. Total biomass averaged 2.5 T/ha for all plots. Additional analysis will be made to relate nutrient content and biomass to fertilizer treatments when nutrient data become available.

Table 5.--Change of Biomass Accumulation (%) by Tree Components With Time.

Tree Components	1977	1979
Leaves	35	25
New branches	11	4
Old branches	12	22
Crown	58	51
Stemwood	35	42
Stembark	7	7
Stems	42	49
Total	100	100

FERTILIZATION OF JUVENILE LOBLOLLY PINE PLANTATIONS IMPACTS ON FUSIFORM RUST INCIDENCE[1/]

Michael B. Kane[2/]

Abstract.--Five-year results on the effect of fertilization of juvenile loblolly pine plantations on the subsequent incidence of fusiform rust (Cronartium fusiforme) are presented. Age at time of treatment, growth response to fertilization, and amounts of rust infection on non-treated plots during the period monitored varied substantially among the 41 stands evaluated. Fertilization had little pronounced effect on subsequent fusiform rust infection although some significant fertilizer-rust relationships were observed: P fertilization increased branch galls in stands responding strongly to P; fertilization with most elements, but in particular K, reduced the rate of rust infection in stands experiencing high levels of increased infection; and N fertilization reduced rust related mortality in stands responding strongly to N. However the magnitude of all these effects was small. Fertilizers can generally be applied to juvenile loblolly pine stands without penalty of substantial increases in fusiform rust.

INTRODUCTION

Fertilization of forest land in the Southeast has received considerable attention in recent years. A comprehensive survey conducted in 1979 listed approximately 450 studies examining fertilization of slash pine (Pinus elliottii var elliottii Engelm.) or loblolly pine (Pinus taeda L.) (NCSFFC 1980). Associated with this substantial research effort has been the increasing use of fertilizers in forest management. Bengtson (1979) reported that approximately 900,000 acres had been fertilized in the Southeast through mid-1978.

While most forest fertilization research has focused upon tree growth response, secondary effects of fertilizer applications have also been examined. The influence of nutrient additons on the incidence of fusiform rust (Cronartium fusiforme Hedgc. & Hunt ex Cumm.) is of particular importance. Fusiform rust is the most serious disease problem affecting management of slash and loblolly pine in much of the Southeast.

Fertilization has been implicated with increased fusiform rust infection of slash and loblolly pine. Hollis et al. (1975) reported significant increases in rust on 11 of 25 slash pine plantations in the Lower Coastal Plain region with additions of nitrogen (N) and/or phosphorus (P) near the time of establishment. Increases in rust incidence generally occurred when fertilization alleviated a deficiency and resulted in substantial growth improvements. Matziris and Zobel (1976) found increased rust severity on 8-year-old loblolly pine following repeated fertilization with P, potassium (K), and lime on three of four sites in the Lower Coastal Plain. Loblolly and slash pine seedlings growing under controlled greenhouse conditions have exhibited both greater rust incidence and accelerated growth with improved soil fertility (Rowan 1977, Rowan and Steinbeck 1977).

While both loblolly pine and slash pine have shown increased rust incidence following fertilization, this association has been less evident with loblolly pine. Dinus and Schmidtling (1971) found that fertilization increased fusiform rust incidence on slash pine while rust frequency on loblolly pine

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growing on the same site was little affected by treatment: both species showed a growth response to fertilization. Site preparation intensity also has a more pronounced effect in increasing rust incidence on slash pine than loblolly pine (Malac and Brightwell 1973).

The research findings cited above show that, to some degree, fertilization of loblolly pine can result in greater rust incidence. These findings, however, are primarily restricted to fertilization at or near the time of planting. What is the impact of fertilizing juvenile loblolly pine stands on subsequent rust incidence? Answering this question was one objective of a regional series of studies established by the North Carolina State Forest Fertilization Cooperative (NCSFFC). Five-year results from this series are the subject of this paper.

METHODS AND PROCEDURES

Forty-one tests were established in 2-9-year-old loblolly pine plantations growing on site prepared land. Study locations ranged from Delaware to Mississippi. Each trial had a randomized complete-block design consisting of a control and four fertilizer treatments replicated four times. The fertilizer treatments tested were selected from eleven different nutrient mixes and varied from study to study. Nitrogen was the principal nutrient examined and was applied at 50 (50N), 100 (100N), and 200 (200N) lbs/acre as ammonium nitrate. Phosphorus was applied at the rate of 50 (50P) lbs/acre in combination with N. Potassium was applied at 50 (50K) lbs/acre in combination with N-P. A mixture of trace elements (TE) was applied in combination with N-P or N-P-K additions. Application rates of TE were as follows: boron-2.4 lbs/acre; cooper-2.4 lbs/acre; iron-14.4 lbs/acre; manganese 6.0 lbs/acre; molybdenum-0.1 lbs/acre.

Height and DBH were determined on all planted loblolly pine trees prior to fertilization and 5 years following fertilizer application. At these same times each tree was catergorized as to the presence to fusiform rust galls according to the following coding scheme:

Code	Tree Characteristic
1	no gall
2	one branch gall
3	two branch galls
4	more than two branch galls
5	one stem gall
6	two stem galls
7	one stem gall & one or more branch gall(s)
8	two stem galls & one or more branch gall(s)
9	lethal stem gall.

Mortality and probable cause of death were noted 5 years following fertilization.

The occurrence of new stem galls, new branch galls, and fusiform rust caused mortality during the 5-year period following study initiation was determined for each tree by comparing the pre-treatment fusiform rust code with the fusiform rust code and mortality information taken 5 years after fertilization. Percent of trees with new stem galls (STEM), percent of trees with new branch galls (BRANCH) and percent of trees dying from fusiform rust (MORTALITY) were then determined for each plot. These measures of infection during the 5-year period following treatment should be sensitive to any fertilization induced changes in susceptibility of loblolly pine to rust. Statistical analyses of rust data were performed following the arcsine $\sqrt{x}$ transformation. An analysis of variance for each of the above fusiform rust variables was performed for each fertilizer trial.

Mean 5-year volume/A, basal area/A, diameter, and height growth were determined for each treatment in each stand.

Rust and growth data from each study were reviewed to isolate responses to specific fertilizer elements tested. These responses were calculated as the difference in 5-year rust infection and tree growth between two treatments differing only in the fertilizer element of interest. For example, if in a particular stand STEM was 15% on the 100N treatment and 12% on control plots then STEM response to N would be 3%. Similarly, if in the same stand STEM was 19% on the 100N-50P treatment then STEM response to P would be 4%.

Data combined from different stands were analyzed to evaluate relationships between rust variables, fertilizer element, growth response, and stand age at time of treatment. These relationships were evaluated for two data sets; one containing all stands and a second containing 12 "high" rust stands. High rust stands are defined here as those stands where the increase in fusiform rust galls on nonfertilized trees during the 5-year assessment period exceeded 15% for STEM and 10% for BRANCH. These stands were located on areas of South Carolina, Georgia, and Alabama where fusiform rust incidence is commonly high (Squillace 1976). Most of these stands were located on well drained sites in the Piedmont and Gulf Coastal Plain.

STAND CHARACTERISTICS

Characteristics of the plantations examined are presented in table 1. The majority of the stands had a low percentage of trees developing new rust galls or dying from rust during the 5 years following study establishment. Mean STEM on control plots averaged 11.4% overall and 28.8% in high rust stands. Mean BRANCH was similar to mean STEM. MORTALITY on control plots averaged 2.5% overall and 5.7% in high rust stands. Both the overall and high rust data sets contain a substantial range of ages, mean heights, amounts of rust at the time of fertilization, and 5-year volume responses to N and P fertilization. Volume responses to K were also highly variable while growth improvements were generally not noted with TE additions. Both K and TE were infrequently tested in high rust stands.

Table 1. Summary of pretreatment stand characteristics, 5-year rust infection without fertilization, and 5-year volume response on all stands (n = 39) and high rust stands (n = 12).

Variable	All Stands Mean	All Stands Std.Dev.	All Stands Range	High Rust Stands Mean	High Rust Stands Std.Dev.	High Rust Stands Range
Pretreatment Stand Characteristics						
Age (yrs)	5.0	1.9	2,9	4.4	1.8	2,9
Mean height (ft)	10.8	4.7	3,20	13.6	3.2	9,20
Trees infected (%)	14.4	16.1	0,63	23.1	17.8	2,57
5-year Infection on Controls Plots						
STEM (%)	11.4	13.0	0,51	28.6	10.1	17,51
BRANCH (%)	12.4	13.8	0,61	28.8	14.9	10,61
MORTALITY (%)	2.5	3.4	0,12	5.7	3.4	2,12
5-year Volume Response						
N (ft^3/A)[1]	92.0	137.0	-195,+392	92.0	15.5	-142,+373
P (ft^3/A)[2]	111.5	96.6	-64,+301	85.3	89.6	-64,+198
K (ft^3/A)[3]	19.8	100.5	-191,+183	182.0	1.4	181,+183
TE (ft^3/A)[4]	-47.4	95.2	-146,+126	-36.5	155	-146,+73

[1] N effect determined in 39 stands; 11 high rust stands.

[2] P effect determined in 30 stands; 8 high rust stands.

[3] K effect determined in 16 stands; 2 high rust stands.

[4] TE effect determined in 11 stands; 2 high rust stands.

RESULTS

Individual Stand Results

Results from analysis of variance of STEM, BRANCH, and MORTALITY for each of the 41 stands are summarized in table 2. Few significant differences among fertilizer treatments were observed in the percent of trees either with new rust galls or dying from rust, even at low levels of probability. Fertilizer treatments were not associated with significant differences (5% level) in STEM in any of the plantations.

Table 2.--Summary of statistical significance of treatment difference in 5-year fusiform rust infection in 41 stands.

Rust Variable	Significance Level[1] <5%	<10%	<25%	>25%
	[no.of stands with fertil. effect]			
STEM	0	0	6	35
BRANCH	2	3	9	32
MORTALITY	1	4	5	36

[1] Probability that treatment differences were a random occurrence rather than a true fertilizer effect.

Significant (5%) differences in BRANCH between fertilizer treatments were observed in only two stands, both of which had low amounts of rust infection during the 5-year period monitored. The nature of the apparent rust response in these two stands differed: BRANCH was increased by N fertilization in one stand but decreased by it in the other. Significant differences in MORTALITY between fertilizer treatments were observed at only one location; MORTALITY was lower in two fertilizer treatments than in the control (3.3%, 0.7% vs 9.5%). No significant treatment differences in STEM or BRANCH were observed in high rust stands.

Combined Stand Results

Effect of Specific Nutrient Elements

Mean responses in 5-year rust infection and ranges of response associated with specific elements are presented in table 3. Mean responses were very small and analysis by paired t tests showed no significant effect. However, there was a considerable range in STEM, BRANCH, and MORTALITY responses associated with the specific elements indicating possible site and stand effects on fusiform response to fertilization.

Table 3. Mean response[1] and range in response in 5-year rust infection associated with N, P, K, and TE additions.

Nutrient	No. of Stands	Rust Variable STEM	BRANCH	MORTALITY
		--(Change in percent infection with nutrient)--		
All Stands				
N	39	-1.2[2] *(-11.6,+7.5)*[3]	0.6 *(-6.4,+14.4)*	-0.2 *(-7.5,+5.0)*
P	30	0.7 *(-13.7,+16.8)*	0.1 *(-15.2,+9.7)*	0.6 *(-2.9,+3.7)*
K	16	-1.4 *(-12.4+3.8)*	-0.7 *(-7.9,+12.0)*	0.2 *(-2.0,+3.4)*
TE	11	1.6 *(-4.3,+11.2)*	0.5 *(-5.7,+8.5)*	-0.6 *(-3.0,+1.7)*
High Rust Stands				
N	11	-3.0 *(-11.6,+7.5)*	0.8 *(-3.7,+7.0)*	-1.4 *(-7.5,+5.0)*
P	8	1.6 *(-7.5,+16.8)*	-1.7 *(-15.2,+7.9)*	1.0 *(-0.7,+3.7)*
K	2	-8.6 *(-12.4,-4.7)*	-4.5 *(-7.9,+1.0)*	0.3 *(-1.2,+1.7)*
TE	2	6.9 *(2.6,+11.2)*	2.0 *(-0.4,+4.4)*	-1.3 *(-1.8,-0.7)*

[1] Mean responses were not significant at the 5% level.

[2] Negative values indicate reduced amounts of rust with nutrient application while positive values indicate increased amounts of rust with nutrient applications.

[3] Range of rust responses.

Relationships Between Stand Factors and Rust Response to Specific Elements.

Stand age at the time of treatment, the amount of rust infection occurring without the application of a specific nutrient, and the degree of growth response to fertilization were hypothesized to be the variables most likely to influence the nature and magnitude of any fertilizer induced change in the frequency of subsequent rust infections and mortality. Correlation coefficients (r) between STEM, BRANCH, and MORTALITY response to N, P, K, and TE fertilization and the above variables are given in table 4. Correlation coefficients could not be determined for relationships with rust response to K or TE in high rust stands because of the lack of sufficient observations.

Stand age at the time of fertilization had little apparent influence on the effect of fertilization on subsequent rust infections.

Table 4. Correlation coefficients (r) between rust response to specific nutrients and stand age at fertilization, 5-year rust infection on base treatments,[1] and 5-year volume response.

	All Stands				High Rust Stands	
	Nutrient					
Variables correlated	N	P	K	TE	N	P
	r					
Age vs.						
STEM Resp	-.15	-.28	-.03	.36	-.09	-.10
BRANCH Resp	.14	.21	-.18	-.46	.07	.62
MORTALITY Resp	-.09	-.18	.10	-.09	-.05	.30
Base TRT Level vs.						
STEM Resp	-.36*	-.22	-.55*	-.25	.15	-.70
BRANCH Resp	-.09	-.45*	-.35	.01	-.11	-.41
MORTALITY Resp	-.44*	-.12	-.33	-.15	.30	-.56
Volume Resp vs.						
STEM Resp	-.13	-.18	-.45	-.64*	-.15	.26
BRANCH Resp	.24	.46*	-.04	-.20	.58	.29
MORTALITY Resp	-.19	-.25	.11	-.39	-.28	.34

* Significant at 5% level.

1/ Base treatments are control for response N, N alone response to P, N-P for response to K and N-P-K for response to TE.

There was generally a negative relationship between rust response to fertilization and the 5-year infection level on the base treatment (control for response, to N, N alone for response to P, N-P for response to K, N-P-K for response to TE). This relationship was significant for STEM and MORTALITY response to N, BRANCH response to P, and STEM response to K. These significant relationships were observed only for the data set containing all stands. The relationship between STEM response to K and STEM on the base treatment (no K) is illustrated in figure 1. Greatest reductions in the amount of trees with new stem galls during the 5 years following K applications occurred in stands experiencing heavier infections during this period.

Volume responses to N and P tended to have a different relationship with BRANCH response than with STEM and MORTALITY response. BRANCH response to fertilizer elements was positively correlated with growth gains from the same fertilizer elements while the reverse associateion was generally apparent for STEM and MORTALITY response. The positive correlation between BRANCH response and volume response to P was significant for the overall data set. This relationship is presented in figure 2. BRANCH, relative to that on the base treatment, tended to increase with increasing volume response to P. Segregation of studies by magnitude of volume response (<75 ft^3/A, 75-150 ft^3/A, & > 150 ft^3/A) also indicated this relationship between growth response and the amount of rust; the percentage of trees with new branch gall was significantly reduced with P additions on low responsive sites while a significant increase in this measure of infection was noted in stands responding strongly to P fertilization. However, the mean increase in the amount of trees with new branch galls on strongly responding sites was relatively small, averaging only 3%.

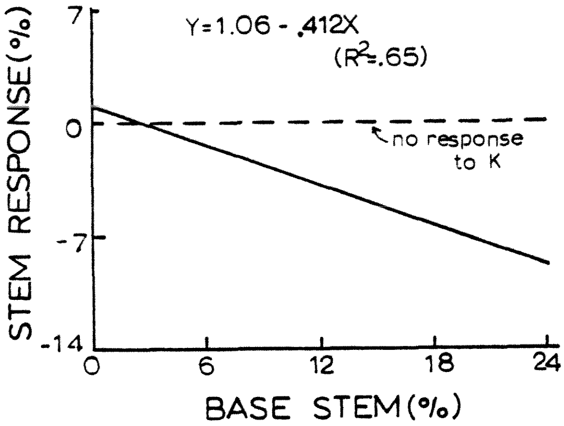

Figure 1.--Relationship between STEM response to K (Y) and STEM on the base treatment (X).

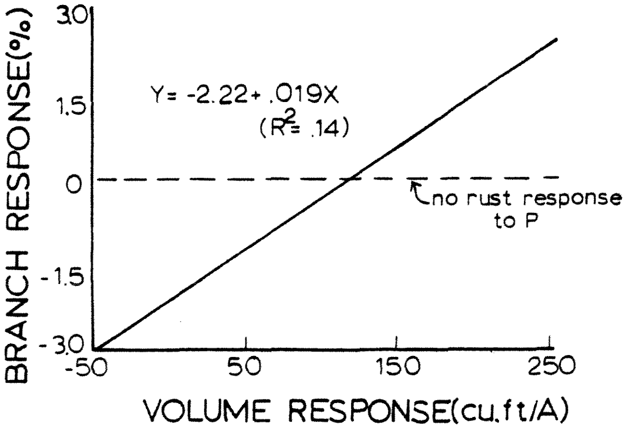

Figure 2.--Relationship between BRANCH response to P(Y) and volume response to P (X).

In contrast to BRANCH response, STEM and MORTALITY response to N and P fertilization was lower on sites showing a greater volume response to these elements, but these relationships were not significant. However, MORTALITY response to N was significantly correlated with basal area response (r = -.32), height response (r = -.34), and diameter response (r = - .37) to N. The relationship between response to N in DBH growth and MORTALITY is presented in figure 3. Nitrogen fertilization can either increase or decrease the amount of trees dying primarily from rust. The amount of mortality attributed to rust tended to increase in stands where N fertilization resulted in growth reductions. Conversely, rust mortality tended to be reduced when N fertilization improved the rate of growth.

Relatively strong negative correlations were observed between volume response and STEM response to K and TE. The significant relationship between response to TE in volume and STEM is illustrated in figure 4. Increases in the percent of trees developing new stem galls generally occurred when TE additions suppressed pine growth.

Five-Year Rust Infection in Stands Strongly Responding to N and P.

Stands most likely to be fertilized are those expected to show the greatest gains in growth. STEM, BRANCH, and MORTALITY in stands responding strongly to N (> 150 ft^3/A) are depicted in figure 5. Differences in STEM and BRANCH associated with N fertilization were not significant and relatively small, even for stands with large increases in rust. The largest difference between treatments was associated with reduced MORTALITY with N in high rust stands.

Five-year rust infection on plots receiving control, N, and N-P treatments in stands showing a substantial volume response to P (> 150 ft^3/A) is illustrated in figure 6. The previously discussed significant increase in BRANCH with additions to these stands is evident. Differences in STEM and MORTALITY on the N and N-P treatments were not significant. Differences in STEM reflect unusual disease levels with N alone on the two high rust stands examined. Both of these stands exhibited moderate growth improvements with N alone.

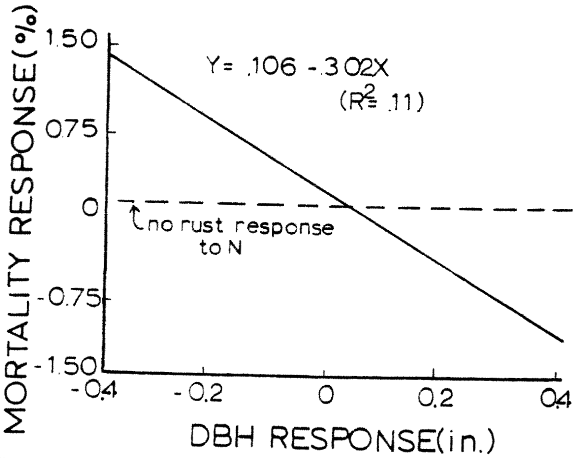

Figure 3.--Relationship between MORTALITY response to N (Y) and response in diameter growth to N (X).

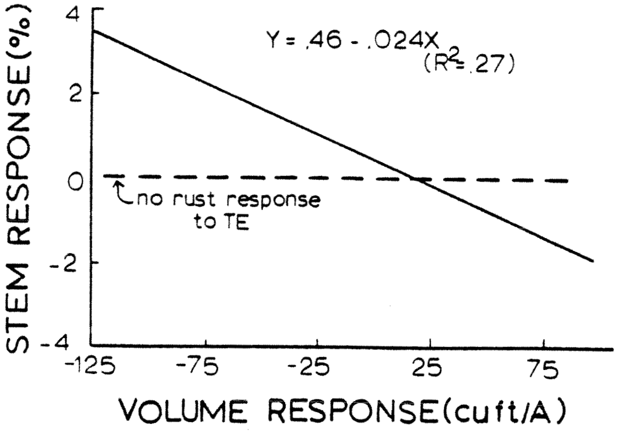

Figure 4.--Relationship between STEM response to TE (Y) and volume response to TE (X).

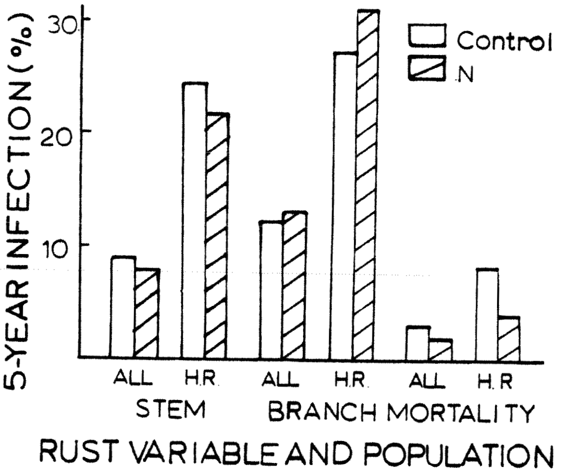

Figure 5.--Mean rust infection and mortality during the 5 years following fertilization in all stands responding strongly to N (n = 11) and in strongly responding high rust (H.R.) stands (n = 3).

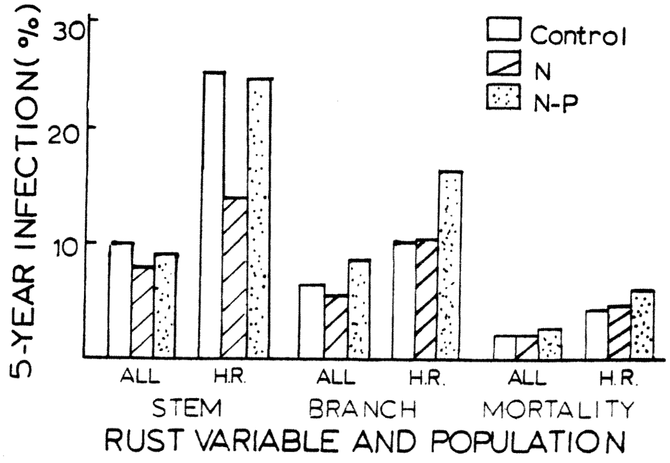

Figure 6.--Mean rust infection and mortality during the 5 years following fertilization in all stands responding strongly to P (n = 10) and in strongly responding high rust (H.R.) stands (n = 2).

DISCUSSION

The results of this study show that fertilization of 2-9-year-old loblolly pine stands generally had little impact on subsequent fusiform rust incidence. The amount of new galls and mortality caused by rust during the 5-year period following fertilization was generally about the same on fertilized and nonfertilized control plots. The specific nutrients evaluated were not associated with consistent or substantial changes in the percent of trees with new galls or the percent of trees dying from rust over all sites.

There were notable trends within the narrow ranges observed in rust response. Where fertilization with P increased the rate of tree growth it also tended to induce an increase in the percent of trees with new branch galls. However the increase in the amount of rust was inconsequential. The second relationship of note was that between tree response to N and the amount of rust related mortality. The apparent reduced mortality on sites responding strongly to N suggests that improved tree vigor has enhanced the ability of trees to survive potentially lethal stem infections. This aspect of the fertilizer-rust relationship requires further study. Finally, there was a general tendency for fertilization, particularly with K, to reduce the amount of subsequent rust infection in stands experiencing relatively high rates of infection.

The 41 stands examined represent a substantial range in stand age at time of fertilization, rust infection during the period monitored, and growth response to fertilization. Many of the stands had low rust infection levels during the 5 years after study initiation. These stands were either 1) located in areas of low rust hazard or 2) located in areas of high rust hazard in stands where the major infection period had preceded fertilization. The results described above support the contention that similar stands can be fertilized without fear of increased rust incidence. More importantly, these results show that fertilization generally did not increase susceptibility to fusiform rust of juvenile loblolly pine stands which experience substantial subsequent infection. The stands with high rates of infection during the 5 year period evaluated were principally on better drained sites in the Piedmont and Gulf Coastal Plain. Growth responses were common in these stands but severe deficiencies were not encountered. It is not known if fertilization of established plantations on severely deficient sites in areas of high rust hazard will result in increases in rust incidence as well as substantial growth gains.

CONCLUSIONS

Fertilization of juvenile loblolly pine stands growing on most sites in the Southeast will not significantly alter the subsequent incidence of fusiform rust. This lack of substantive effect has been demonstrated for a variety of combinations of stand age at treatment, infection level on nonfertilized plots during the period evaluated, and the magnitude of growth response to fertilization. While large consistent changes in fusiform rust incidence following fertilization were not observed, results have shown that fertilization can increase or decrease subsequent rust severity. The proportion of trees developing new branch galls was increased when P resulted in strong growth responses. On the other hand, fertilization generally tended to reduce the amount of subsequent infection and mortality in stands with relatively high rates of infection and mortality during the period evaluated. Rust related mortality also tended to be reduced when N fertilization stimulated growth. These findings apply to many stands in the Southeast but do not directly apply to fertilization of stands on severely nutrient deficient sites in high rust areas; such stands were not evaluated in this study.

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USE OF LEGUMES IN SOUTHEASTERN FORESTRY RESEARCH[1]

Jacques R. Jorgensen[2]

Abstract.--Legumes have been established on a wide range of sites in the Southeast to determine their adaptability, fertility requirements, and influence on the site and on the growth of recently planted trees. The majority of legumes are not suitable for forest planting. The winter annual subterranean clovers and the summer annual and perennial lespedezas are the legumes best adapted to the competition, low degree of site preparation, and adverse soil conditions of the typical forest planting. Legumes have responded to P fertilization, with source of P important on some sites. Legumes increased site N and increased the N content of loblolly pine foliage.

INTRODUCTION

Nitrogen (N) is essential for all living organisms. Forest trees respond to this element more frequently than to any other fertilizer nutrient. However, response to N or to any element is limited by deficiencies of other nutrients and other factors such as moisture and sunlight. There is a trend—an economic necessity—toward supplemental forest fertilization for sites where growth potential is limited by those factors that can be economically manipulated. The economic benefits of forest fertilization were realized in the 1960's and early 1970's when chemical fertilizers were inexpensive relative to their benefits. In the mid-1970's, however, the glut of low-priced N fertilizer came to an end for a number of reasons, primarily because of the direct relationship between chemically transforming atmospheric N into a form usable by plants and the cost of energy.

The increasing cost and potential restriction on the use of energy for the production of fertilizer has renewed interest in another N source, biologically fixed N, one that has been known but not understood since the development of plant cultivation in ancient civilizations. The initial attempts to integrate the use of legumes into forestry began in central Europe in the first half of the twentieth century where lupines were used experimentally to aid in the rejuvenation of degraded forest soils. More recently, interest in biological N fixation has spread to Australia and New Zealand where it has been used to aid soil stabilization and to improve soil fertility in general. Until recent years, in the United States, biological N fixation in forestry has usually been practiced through the use of nurse crops such as black locust or various alders that would later be removed when the more desirable species were established. The majority of the early plantings with these species were not markedly successful due to poor site conditions and improper selection of the nurse crops which often outgrew the species desired for the final stand.

WORK AT THE SOUTHEASTERN FOREST EXPERIMENT STATION

In 1973, limited work was begun to determine if N-fixing plants could contribute to the N economy of a site and eventually to the growth of planted pines and hardwoods. Both exotic and native N-fixing plants were used in a series of field tests in which most of the candidate plants failed to become established. In 1975, a screening program was introduced to select species that could adapt to the severe conditions often found in the forest situation. Initially, we established four primary criteria and several secondary criteria for use in the selection of N-fixing plants. The primary criteria were:

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Fix nitrogen--Candidate plants should be able to fix significant quantities of nitrogen, with 50 to 100 kg of N/ha taken as the minimum annual rate. This rate of fixation should be maintained for 3 to 5 years to provide an economic return.

Tolerate infertile, acid soils--Plants should be able to grow in soils fertilized primarily to benefit tree growth. In most instances, this would exclude lime and potassium additions to the soil where pines are to be grown.

Be easy to establish--Seed should germinate quickly and seedlings be sufficiently vigorous to establish themselves in spite of poor soil conditions and weed competition.

Be self-maintaining--Plants need to be perennials or reseeding annuals capable of establishing dense vigorous stands. However, a balance must be established between the vigor of the N-fixing plant and the final crop tree. No more kudzus!

Secondary criteria included:

Shade tolerance--The greater the shade tolerance, the longer the period of N fixation.

Growth that occurs primarily in the fall, winter, and early spring--Growth during the cool season reduces the competition between the trees and N-fixing crop for moisture and nutrients. This is especially important in hardwood plantations.

Weed control--When cover crops are used in hardwood plantations, weed control is an especially useful feature. A dense stand of plants or plant residues in late spring or early summer inhibits weed growth, which reduces competition and the need for cultivation. A cover of plants on the soil surface throughout the year will also reduce erosion.

Benefit (or unharmful) to wildlife--Some N-fixing plants are of no direct benefit to wildlife and may even be poisonous. However, many species have both the ability to fix N and produce valuable seed and forage for wildlife.

Lack of interference with forest management--Trailing climbing vines, flammable waxy leaves, spinney leaves and branches, and shrubs that form impenetrable thickets are all characteristics unfavorable to forest management. Wax myrtle, kudzu, some lespedezas, and European gorse each have some of these undesirable features.

The ideal plant for forest sites would be a herbaceous, fast-growing winter perennial with a low profile that is esthetically attractive. It should be able to grow and compete with weeds with little site preparation or fertilizer, fix copious amounts of N, and provide seed, forage, and cover for wildlife over a period of several years. We attempted to identify this ideal plant through screening, first by reviewing the literature and then by using the more promising candidates in field trials. In the field trials, we tested three factors: 1) the plant itself, 2) the relationship of plant growth to soil fertility, and 3) the relationship between the legume and tree growth and the factors that influence this growth.

Plant Selection

Although there are about 18,000 species of legumes, of which about 200 are found in the Southeast, we have confined our work to those which are agronomically important. The reasons include both knowledge of the plant and seed availability. Much is known about the management of agronomic legumes for maximum growth and about their N-fixing capabilities. Except in a very general way, relatively little is known of the growth requirements or the N-fixing capabilities of the wild legumes, but they do offer a fertile field for investigation. Seed availability also plays an important part in N-fixing plant selection. Commercially produced seed available at low prices eliminates one step that would be necessary if a wild legume had been selected. There are instances where plants have desirable characteristics—dwarf lespedezas and desmodiums are examples—but seed production is so limited that they are essentially eliminated from large-scale planting trials.

Over 70 species and varieties of N-fixing plants have been field tested to determine their suitability for use in forestry (table 1). The majority of these plants have been agronomically important legumes and, as expected, most of these plants are not adapted to forest conditions. Of the plants examined, only about a dozen are still actively under consideration, although additional species and varieties are tested annually.

Table 1.--Results of species and varietal trials 1976-79

Plant group	No. of species and varieties examined	Results	
		Testing discontinued	Testing continued
Lupine	14	14	0
Clover	24	19	5
Vetch	4	4	0
Lespedeza	9	2	7
Other	20	1/	1/

1/ Testing of several species continues but is often limited by availability of seed.

Testing consists of growing the plants under one or more soil and fertilizer regimes. The number of trials, which total over 200, range from over 20 devoted to 'Mt. Barker' subterranean clover to one trial with mung beans. The number of trials are directly related to the potential of the plant. The primary reasons for failures are: 1) the plants are not adapted to harsh site conditions, 2) disease, and 3) failure of annuals to regenerate.

One of the most common problems in establishment is with small seed which produce tiny plants that are insufficiently vigorous to adapt themselves to adverse conditions. In some instances, as with lupines, the testing site was unsuitable and poor growth, accompanied by root rots and leaf diseases, eliminated most of the plants before maturity. Vetch stands were usually not dense enough to compete with weeds and, within a few years, the legume was eliminated. Browsing causes severe problems in the establishment and growth of many species.

Two groups of plants—clovers and lespedezas—have produced the majority of potentially useful plants. Within these two groups, the following species or varieties are promising:

Subterranean Clover—'Mt. Barker' and 'Tallarook' Varieties

'Mt. Barker' and 'Tallarook' subterranean clovers are midseason and later winter annuals in which most growth is completed by late May. Good stands of these plants will contain over 200 kg of N/ha, the majority of which will have been fixed biologically. Subterranean clovers are tolerant of acid, low-fertility soils in which most other clovers fail to grow. They are bothered by few diseases and insect pests. The crop has a spreading, low profile that is somewhat resistant to browsing. A low, dense mat of plant remains persists through much of the summer and can exert a high degree of weed control. These varieties are prolific seeders. The majority of seeds are produced in burrs which bury themselves in the soil. Seed are desirable food for birds and other wildlife.

Arrowleaf Clover—'Yuchii' and 'Meechee' Varieties

These are tall, winter annuals in which growth may continue through June. Dense stands of these plants can be obtained from initial seedings. In many instances, successful volunteer stands have failed due to poor seed set, distribution, or other factors. Arrowleaf clovers appear more sensitive to site conditions, and more subject to disease than the subclovers.

Rose Clover

A low-profile, upright clover that has persisted and formed dense stands in one study. The plant appears tolerant of acid, low-fertility soil, and needs to be further tested.

Sericea Lespedeza

This herbaceous summer-growing perennial is easy to establish, tolerant of adverse soil conditions, and not affected by disease and insects. It has been used agriculturally for soil improvement and can fix considerable quantities of N. Sericea is somewhat shade tolerant and produces hard seed which persist for many years in the forest floor. The forage and seed of common sericea are of limited value to wildlife because of their high tannin content, although varieties have been developed which are lower in tannin. If not properly managed, sericea can compete vigorously with planted trees.

Virgata Lespedeza—'Ambro' Variety

This low-growing, perennial lespedeza, recently released by the Soil Conservation Service, is less aggressive than sericea. Stand establishment may be limited by slow-growing seedlings during the first year.

Thunbergii Lespedeza—'VA-70' Variety

A tall-growing wood shrub that is easy to establish and is tolerant of adverse soil conditions. Seed are valuable for wildlife, but forage is not extensively browsed. N-fixing capacity is about equal to that of sericea.

Fertilization

There are three factors to be considered when legumes and other N-fixing plants are fertilized: 1) legume growth desired, 2) nutrient recycling, and 3) the nutrient needs of the trees.

Small quantities of fertilizer applied to forest-grown legumes may be sufficient for sustained crops, whereas the same quantity of fertilizer on the agronomic crop may result in stand failure. In agronomy, forage is removed by grazing or by hay production. This forage contains a portion of the fertilizer applied to the site to increase production. In forestry, except through wildlife consumption and losses through leaching, fertilizer elements taken up by the legumes remain on the site and, provided that they are in an available form, can be reused without limit. This is the same nutrient cycling principle that enables continued harvest and growth of forest stands so long as the harvest does not exceed normal nutrient inputs to the site.

Since trees are the primary crop and legumes the secondary, the major fertilizer application to the legume should also benefit the trees. Pines have little or no positive response to lime or to potassium (K), so only under special circumstances, where other than simple N accretion is desired, would large applications of these elements be justified. Fortunately, trees often respond to phosphorus (P), and we have found that the application of this element is essential for the growth and development of most legume stands. In greenhouse trials, three varieties of clover, hairy vetch, and Austrian winter pea were grown on Coxville sandy clay loam, a clayey, poorly drained, high organic matter soil, and also on Appling loamy sand (Jorgensen 1978).[3] On these soils, legumes failed to grow when no fertilizer was applied but grew equally well with ground rock phosphate (GRP) alone or with P + K + lime applications. Plants grown on Wickham loamy sand, a soil relatively high in available P and with a pH of 5.5, produced a crop without the addition of fertilizer but the addition of P alone or P + K + lime significantly increased yield. Two nonagronomic legumes, false anil indigo and partridge pea, grown on the same three soils showed much less response to the fertilizers than did the agronomic legumes. Neither species responded to fertilizers on the Wickham soil. Partridge pea responded to fertilizer on the Coxville and Appling soils, but also produced acceptable yields without the fertilizer additions.

Field installations of legumes have produced results similar to those obtained in greenhouse trials. The essential fertilizer ingredient has been P. Stands of annual legumes have usually failed the first year without a P application. When perennial plants are grown without a P application, the initial stand is gradually eliminated by the more competitive weeds.

The rate of P application in most studies has been about 112 kg/ha. This amount is usually sufficient for the study period which lasted 4 years in one instance. In other studies where P was the variable, there was no difference in legume growth on well-drained soils when from 56 to 280 kg/ha of P were applied.

Phosphorus applied as GRP has generally elicited a better legume response than it has as triple superphosphate (TSP), especially where some drainage problems exist. The better response with GRP may be the result of its greater calcium content or due to the availability of the P over a long period of time. In a recent study in the South Carolina Coastal Plain, growth of subterranean clover was better with GRP than with TSP but the addition of 4,480 kg of lime/ha with the TSP was better than the GRP alone.[4] Growth of the subterranean clover with GRP alone would have been satisfactory in a pine plantation where weed control was not absolutely necessary and liming would not have benefited the trees. In this particular instance, the experimental treatment was adjusted to that of a hardwood plantation in which the lime application was desirable and weed control was necessary.

Measurements to determine the influence of P on legume biomass production and N fixation are being carried out in a loblolly pine plantation planted with sericea lespedeza (tables 2, 3). The addition of P without legume had no appreciable influence on either the amount of nonwoody biomass (weeds) produced or the N it contained. Annual biomass production on control and P only plots over a 3-year period averaged 5.2 t of weeds/ha which contained 40 kg of N/ha. Sericea sown without P produced little biomass, and production nearly ceased by the fourth year.

Table 2.--Influence of fertilization and legumes on nonwoody biomass production

Treatment	Years since establishment	Biomass: Surface litter	Biomass: Weed	Biomass: Legume	Total
		t/ha			
Control	2	0	3.8	0	3.8
	4	0	5.6	0	5.6
Phosphorus[1]	2	0	4.1	0	4.1
	4	0	7.1	0	7.1
Sericea	2	0	2.3	.3	2.6
	4	0	4.5	.1	4.5
Sericea + P[1]	2	0	.8	6.6	7.4
	4	15.6	.7	9.0	25.3

[1] 89 kg/ha of P applied as ground rock phosphate.

Table 3.--Influence of fertilization and legumes on nitrogen in soil and in nonwoody biomass

Treatment	Years since establishment	Soil depth (cm) 0-10	Soil depth (cm) 10-20	Soil depth (cm) 0-20	Biomass: Surface litter	Biomass: Weed	Biomass: Legume	Total biomass	Soil & biomass
		kg N/ha							
Control	2	944	536	1,488	0	25	0	25	1,513
	4	1,201	771	1,972	0	47	0	47	2,019
Phosphorus[1]	2	902	428	1,330	0	27	0	27	1,357
	4	1,282	658	1,940	0	61	0	61	2,001
Sericea	2	926	504	1,430	0	18	4	22	1,452
	4	1,061	672	1,733	0	38	1	39	1,772
Sericea + P[1]	2	1,100	545	1,645	0	8	121	129	1,774
	4	1,372	698	2,070	183	10	127	320	2,390

[1] 89 kg/ha of P applied as ground rock phosphate.

The addition of P to sericea plots resulted in an increase of over 400 kg of N/ha in the system by the fourth year, compared to plots without this combination. Most of the N increase was related to the living legume biomass and litter. Total biomass on the sericea + P plots amounted to 25 t/ha, nearly five times that of control plots. The amount of N in biomass was about the same the third and fourth years, but the distribution changed. The largest portion was in the living biomass during the third year but in litter by the end of the fourth year.

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[3] Jorgensen, J. R. 1978. Growth of legumes on forest soils fertilized at low rates. USDA For. Serv., Res. Note SE-251, 7 p. Southeast. For. Exp. Stn., Asheville, N.C.

[4] Personal communication, D. Gerwig, Westvaco, Summerville, S.C.

Sampling variability made it difficult to determine if there had been any increase in soil N. The top 20 cm of soil from plots with sericea + P contained 98 kg more of N than did the control plot, but this was not significant at the 5 percent level. Neither were there significant differences between the two treatments for soil layers of 0 to 10 and 10 to 20 cm.

Nitrogen fixation on plots with sericea + P occurred; however, the amount of fixation cannot be accurately determined due to large sampling variation for both nonwoody biomass and soil and also because of the unknown quantity of N taken up by the woody biomass—primarily loblolly pine—on the site. It appears, though, that through the fourth year a well-established sericea stand can add about 100 kg of N/ha/year to a site. But there are still questions about the utilization of this N.

Effect of Legumes on Tree Growth and Nutrient Uptake

Trees initially respond to N fixed by legumes by increasing foliar N. Foliage of sweetgum seedlings on winter annual legume plots had greater N content when sampled a few months after the death of the legumes than did foliage of control seedlings (table 4). Sweetgum grown with no N fertilizers, legumes, or cultivation had N concentrations of 1.53 percent in green leaves and 0.92 percent in red leaves. However, when subterranean and arrowleaf clovers were grown with the uncultivated sweetgum, the N content of their green leaves averaged 2.12 percent and red leaves averaged 1.64 percent. Operational fertilization, in which 50.4 kg/ha of P and 44.7 kg/ha of N as diammonium phosphate was placed in the planting slit and the trees cultivated, produced green leaves with N concentrations of 2.3 percent and no red leaves. This suggests that even though legumes contribute to the N economy, the supply generated during one growing is insufficient for optimum growth and the elimination of red leaves. Low K content of the red leaves was related to their low N content. Phosphorus, calcium, and magnesium contents of leaves were unrelated to leaf color or N concentration.

Table 4.--Nutrient concentration in green and red sweetgum leaves of 1-year-old plants following one rotation of winter annual clover

Treatment	N		P		K		Ca		Mg	
	G1/	R1/	G	R	G	R	G	R	G	R
	Percent									
P, K + lime2/	1.53	0.92	0.19	0.14	0.43	0.22	0.52	0.59	0.52	0.50
Subclover + P + K + lime2/	2.08	1.32	.23	.19	.35	.23	.52	.60	.47	.47
Arrowleaf clover + P + K + lime2/	2.17	1.96	.23	.26	.44	.36	.46	.43	.41	.42
Operational treatment3/	2.30	--	.18	--	.41	--	.23	--	.12	--

1/ G = Green leaves, R = Red leaves.

2/ 56 kg/ha of P as triple superphosphate + 56 kg/ha of K as potassium chloride + 2,240 kg/ha of lime, no cultivation.

3/ 50.4 kg of P/ha and 44.7 kg of N/ha as diammonium phosphate in planting slit and cultivation.

Over a 4-year period, perennial lespedezas have had a positive influence on the nutrient content of loblolly pine foliage (table 5). These trees, planted on a site 90 soil, responded to a sericea-P fertilization combination by increasing foliar N about 10 percent over that found in controls (1.52 vs. 1.37) at the end of the fifth year. The N concentration of controls was higher than 1.2-percent value taken as the limit above which a large response to N fertilization is not expected. This upper limit was exceeded each year measurements were made, regardless of treatment. Phosphorus did not behave like N; in control plots it gradually decreased from 0.11 percent in the foliage of 3-year-old trees to 0.07 percent 2 years later. The latter concentration is below the 0.09 percent deficiency level at which trees would be expected to respond to P applications, all other elements being sufficient. Calcium and K levels in needles were not influenced by legume treatment.

Table 5.--Nutrient concentration in loblolly pine needles, by tree age1/ and cultural treatment

Treatment	Age 3				Age 4				Age 5			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
	Percent											
Control	1.30	0.11	0.52	0.16	1.43	0.10	0.55	0.22	1.39	0.07	0.46	0.20
P2/	1.38	.13	.51	.17	1.47	.12	.52	.22	1.34	.11	.48	.22
Sericea	1.36	.11	.54	.17	1.46	.10	.53	.20	1.39	.07	.48	.18
Sericea + P2/	1.46	.14	.56	.19	1.52	.12	.55	.23	1.57	.11	.53	.19

1/ Growing seasons since plantation establishment.

2/ 89 kg/ha of P as ground rock phosphate.

Unfortunately, the site chosen to study the growth response of loblolly pine to lespedeza and P was not sufficiently deficient to produce an immediate treatment effect (table 6). For the first 3 years, the application of P or growing sericea had no influence on the diameter or height of trees. During the fifth year, trees which had a P application with sericea grew significantly more than the trees on the control plots and plots with sericea only. Where only P was applied, diameter and height growth were intermediate—not being significantly different from either the slower growing controls and sericea only treatments or the faster growing trees in sericea + P plots. At no time did the dense stands of sericea have a negative influence on tree growth.

Since the tree's growth response to fertilizer is related to the nutrient content of its needles, no P response is expected when the P content of the needles exceeds 0.09 percent. This concentration occurred through age 4 in loblolly pine. In the fifth year, when P content of the needles dropped to 0.07 percent on unfertilized plots, P became a growth-limiting element and additional growth could be expected. The additional growth was obtained from only one treatment—that in which

Table 6.--Height and diameter of loblolly pine by tree, age[1] and cultural treatment

Treatment	Height at age:				Diameter[2] at age:		
	2	3	4	5[3]	3	4	5[3]
	m				cm		
Control	1.01	1.95	2.80	3.94a	3.8	5.5	6.7a
Phosphorus[4]	1.06	2.00	2.84	4.17ab	3.5	5.6	7.1ab
Sericea	.98	1.91	2.82	3.98a	3.8	5.2	6.8a
Sericea + P[4]	1.00	1.95	2.90	4.26b	3.9	5.4	7.2b

[1] Growing seasons since plantation establishment.

[2] Diameter measured 15 cm aboveground at ages 3 and 4; diameter at breast height at age 5.

[3] Means followed by the same letters do not differ significantly at the 5 percent level.

[4] 89 kg/ha of P as ground rock phosphate.

P fertilizer maintained foliar P above the deficiency level and foliar N was elevated by the dense stand of sericea. It is hoped that the response of loblolly pine to the sericea-P combination will continue through the early years of stand closure and a positive economic benefit will be derived.

OTHER AREAS OF INVESTIGATION

Most forage plantings will be made on soils that are relatively inhospitable to legumes. In agronomic plantings, factors such as low pH, low fertility, and low soil moisture can be controlled to some extent to produce an environment favorable not only to the legume, but also to the rhizobial symbiont. In forest plantings, these factors are largely uncontrolled, negatively influencing the rhizobial symbiont, and resulting in poor nodulation and legume stand failure for the lack of N fixation. Since it is impractical to control the soil environment, an alternative is to select rhizobia that can survive adverse soil conditions, infect the emerging legume plant, and efficiently fix large amounts of N. The selection of microorganism strain with these capacities has only recently begun in forest-oriented research.[5] Progress has been made and will continue as long as there is an interest in the use of legumes to supplement or supplant N fertilizers in the forest.

Recent agronomic investigations have reported improved legume growth and N fixation when plants were inoculated with certain strains of mycorrhizae in addition to the rhizobial symbiont. So far as is known, no investigations involving mycorrhizae and forest-oriented legume plantings are being carried out. This is a desirable field for investigation since the mycorrhizae can aid the higher plant in nutrient gathering, an important consideration on infertile forest soils.

At the present time, legumes are being established experimentally on well-prepared disked seedbeds. Disking serves three purposes: 1) controls competition, 2) mixes fertilizer with the soil, and 3) prepares a seedbed. Seedbed preparation is especially important for providing good contact between the seed and the mineral soil, which improves moisture uptake and, of equal importance, protects the rhizobium inoculum that has been applied to the legume seed. In most instances few rhizobia would survive if seed were sowed on unprepared soil surfaces and exposed to the elements. To avoid expensive site preparation yet retain high populations of rhizobia surrounding the seed, the seed could be coated with a material that would protect the rhizobium until conditions are favorable for seed germination. Coatings have also been reported to increase seed germination and improve survival and early growth of seedlings. Studies on the use of coated seed and minimum site preparation will be undertaken in the near future.

A number of other topics need investigation to improve the reliability of biologic N fixation and its economic attractiveness. These include the investigation of nutritional factors (minor elements), browsing and other use of plants by animals, utilization of legumes for weed control in hardwood plantations, the effects of disease and parasitic plants on N-fixing plants, esthetics of plantation establishment, nutrition conservation and cycling efficiency (especially on sandy sites), erosion control, effect of and control of competition promoted by N fixation, and the influence of planting date on legume establishment and yield. The list of topics can continue ad infinitum.

CONCLUSIONS

A small beginning has been made that shows legumes can be established without excessive preparation of forest sites. Legumes on forest sites can fix considerable quantities of N, some of which is readily taken up by the trees and reflected in the N content of their leaves. In one instance, N fixation has been associated with increased height and diameter of loblolly pine. However, much more work needs to be done before N-fixing plants can be recommended as an alternative to N fertilization as a routine management practice.

Conversion factors: metric to English

Multiply	By	To obtain
kg	2.20	Pounds
ha	2.47	Acres
cm	0.394	Inches
m	3.28	Feet
t (metric ton)	1.102	Pounds

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[5] Personal communication, C. B. Davey, School of Forestry, N.C. State University, Raleigh, N.C.

Scientific Names of Plants Used in Text

Common Name	Scientific Name
Alder	*Alnus* spp.
Bean, mung	*Vigna radiata* (L.) Wilczek var. *radiata*
Clover	*Trifolium* spp.
Clover, arrowleaf	*Trifoloum vesiculosum* Savi
Clover, rose	*Trifolium hirtum* All.
Clover, subterranean	*Trifolium subterraneum* L.
Desmodium	*Desmodium* spp.
Gorse, European	*Ulex europaeus* L.
Indigo, false anil	*Indigofera pseudotinctoria* Matsun.
Kudzu	*Pueraria lobata* (Willd.) Ohwi
Lespedeza	*Lespedeza* spp.
Lespedeza, sericea	*Lespedeza cuneata* (Dum.) G. Don
Lespedeza, thunbergii	*Lespedeza thunbergii* (DC.) Nakai
Lespedeza, virgata	*Lespedeza virgata* DC.
Locust, black	*Robinia pseudoacacia* L.
Lupine	*Lupinus* spp.
Myrtle, wax	*Myrica cerifera* L.
Pea, Austrian winter	*Pisum sativum* var. *arvense* (L.) Poir.
Pea, partridge	*Cassia fasciculata* Michx.
Pine, loblolly	*Pinus taeda* L.
Sweetgum	*Liquidambar styraciflua* L.
Vetch	*Vicia* spp.
Vetch, hairy	*Vicia villosa* Roth

CAN FERTILIZATION OF LOBLOLLY PINE ON WET SITES REDUCE THE NEED FOR DRAINAGE [1]

O. Gordon Langdon and William H. McKee, Jr. [2]

Abstract.--Available evidence suggests a working hypothesis that fertilization of certain wet sites deficient in phosphorus, calcium, nitrogen, and/or other nutrients can reduce the need for drainage to improve the growth of loblolly and slash pines. The evidence is strong enough for landowners to pilot-test the concept at a relatively low cost on wet sites which appear to have nutrient deficiencies.

Additional Keywords: Slash pine, bedding, soil-site, limiting factors, site productivity, nutrients, soils moisture, soil chemistry, waterlogging, Pinus taeda, P. elliottii.

Loblolly pine (*Pinus taeda* L.) thrives on many very wet sites but does poorly on others of similar wetness such as wet flats or savannahs. What makes one site excellent for growth and the other very poor? Why do drainage and bedding dramatically increase growth on certain wet sites and not on others? These questions illustrate the dilemma that many foresters face as they put the results of research on drainage, bedding, and soil-site classification into practice.

A common assumption has been that excess moisture is the factor most limiting to growth on very wet sites, but recent work (Ralston 1965, Terry and Hughes 1975, McKee 1977, and Langdon and Hatchell 1977) shows that, at least in some instances, nutrients or other factors may be more limiting than excess moisture. These findings prompted the very practical question posed by our title: "Can fertilization of loblolly pine on wet sites reduce the need for drainage?" If fertilization could be substituted for drainage on identifiable sites, it would be a very attractive alternative because drainage costs are apt to be 3 or 4 times fertilization costs.

Our paper presents affirmative evidence from the literature on the question of substituting fertilization for drainage. It also proposes a working hypothesis on the relationships of site productivity to moisture and nutrients. Our evidence is derived from silvicultural studies that show effects of drainage, bedding, and fertilization on tree growth; from soil-site work that shows the relationships of soil properties to tree growth; and from basic studies of soil chemistry and tree nutrition that reveal some of the interacting effects of soil waterlogging and tree physiology on tree growth. Both practical and theoretical implications of the hypothesis are examined. Our review which follows is intended to give the reader the background and basis for our conclusions.

DRAINAGE IMPROVES GROWTH

Draining very wet sites such as bays and pocosins of the Atlantic Coastal Plan has dramatically increased growth of loblolly pine. On the Hofmann Experimental Forest in eastern North Caroline on a Portsmouth soil, Pruitt (1947), Miller and Maki (1957), and Maki (1955, 1968, 1971) showed that drainage greatly increased the yield of loblolly pine. Yields on drained plots (2600 cu. ft./ac.) at age 17 were 13 times greater than those on undrained plots (199 cu. ft./ac.). In a similar study in North Carolina, Terry and Hughes (1975) demonstrated comparable responses on a Bayboro-Bladen soil association: At age 13, yield of loblolly pine on drained areas (800 cu. ft./ac.) was 10.5 times greater than on undrained areas (76 cu. ft./ac.).

Such responses are not limited to loblolly pine. In a study in Georgia on a Bayboro-Bladen-

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[1] This paper is based on talks given in Raleigh, NC, November 8, 1977, at the Site Preparation Workshop (East) sponsored by the USDA For. Serv., Southeast. Area State and Private Forestry, and the North Carolina Forest Service, at the Edisto Chapter Meeting, Soc. of Amer. For., Feb. 9, 1978, in Charleston, SC, and at the For. Tree Nutrition Workshop, May 2, 1979, Bainbridge, Ga.

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Coxville soil association, Brightwell (1973) showed that drainage of 7-year-old slash pine (*P. elliottii* Engelm.) increased the average tree growth by 4.2 fold at age 15. Thus, considerable evidence is accumulating that lowering the average water table 1 to 1½ feet on extremely wet sites with poor natural drainage greatly increases the growth of both loblolly and slash pines.

SOIL-SITE WORK

In marked contrast to the results of drainage studies, soil-site work by Coile (1952), Gaiser (1950), and Metz (1950) in the Atlantic Coastal Plain of Virginia and the Carolinas showed that site quality for loblolly pine was higher on poorly drained than on well-drained soils. As Wahlenberg (1960) has pointed out, this trend, although surprising and seemingly paradoxical, was also apparent in Louisiana (Grigsby 1952).

How can we explain the apparently contradictory results from the drainage and soil-site work? One possible explanation for the effect of soil drainage on productivity is that the response is curvilinear as one goes from well to poorly drained sites, that it peaks at some level of natural drainage and then drops off sharply, that Coile and his colleagues were working at one end of the curve, and that those involved in drainage were working at the other. This explanation is probably accurate, but how then do we explain productivity differences in the same drainage class or even in the same soil series (Soil Conservation Service 1975)?

In three flatwood soil series--Craven, Wahee, and Meggett--we accounted for between 60 and 74 percent of the variation in site index of loblolly pine on the basis of soil properties (McKee 1977). Current Soil Conservation Service guidelines place these three series in drainage classes ranging from moderately well to poor on the basis of the physical and chemical properties of the soil. Nitrogen, clay content, and soil pH in the A1 horizon accounted for 60 percent of the variation in site index on moderately well drained Craven soil; nitrogen, calcium, and phosphorus in the B2 horizon accounted for 64 percent of the variation on the somewhat poorly drained Wahee soils; and percentage of sand and available phosphorus in the A1 horizon accounted for 74 percent of the variation in site index on the poorly drained Meggett soil. Within a series, these soils varied as much as ± 20 feet in site index, indicating that chemical properties and texture have a pronounced effect on site productivity.

BEDDING RESPONSES

Growth response of slash and loblolly pines to bedding, which provides microsite drainage, ranges from excellent to none. Bethune (1963), Langdon (1956, 1962), Malac and Brightwell (1973), Mann and Derr (1970), McMinn (1969), McKee and Shoulders (1970), and Pritchett and Smith (1974) have reported excellent response of slash and loblolly pines to bedding at young ages on wet sites. However, Haines, et al. (1975) and Lennartz and McMinn (1973) have reported that bedding responses may decrease as a stand grows older. And Derr and Mann (1970), Klawitter (1970), Malac and Brightwell (1973), and Terry and Hughes (1975) have reported little or no response on specific sites.

Explanations by the authors for these varying responses of slash and loblolly pines to bedding on wet sites have been largely speculative. When responses are positive, the reasons given include improved drainage, better soil aeration, better weed control, concentration of topsoil in the bed, and increased amount and availability of nutrients. When responses are negative, such reasons as the creation of a drought stress during summer months and poor bed construction are proposed.

The negative responses can be partially explained by the results of Terry and Hughes' (1975) factorially designed study of bedding and phosphate fertilization. They found that bedding on a poorly drained Bladen soil increased growth of loblolly pine only by 4 percent, that phosphate fertilization increased growth by 58 percent, and that bedding combined with phosphate fertilization increased growth by 168 percent. Their results illustrate Liebeg's law of the minimum as described by Kramer and Kozlowski (1960, p. 468):

> "The principle of limiting factors, as proposed by Blackman, states that if a process is affected by a number of separate factors, its rate is limited by that factor which is present in least amount relative to its minimum requirement."

Thus, in Terry and Hughes' study, lack of phosphorus was so limiting that the drainage provided by bedding did not increase growth until the nutrient deficiency was corrected.

The interaction of drainage and nutrition has been reported for soils in the Atlantic and Gulf Coastal Plain. Pritchett and Llewellyn (1966) observed that a surface application of phosphorus stimulated slash pine growth on imperfectly and poorly drained soils deficient in this element but had less effect on phosphorus-deficient soils that were better drained. Mann and McGilvray (1974) showed a similar response in northwest Florida with direct-seeded slash pine which at 8 years had responded about equally in height growth to bedding and phosphorus fertilization on poorly and very poorly drained Plummer soils. An additive response was found when bedding and phosphorus were combined. On the better drained Plummer soils, the trees did not respond to phosphorus.

TREE NUTRITION

Problems with nutrition on poorly drained soils are not unique to forestry. Van't Woudt and Hagan (1957) indicate that most field crops injured by high water tables have much higher nutrient demands when the soil is poorly aerated. Crops such as rice, which are adapted to poor soil aeration, are an exception. The reasons for increased nutrient requirement of trees and field crops subjected to waterlogging are not completely understood, but the higher nutrient requirement may result from restricted root systems. Kramer (1951a) found that flooding and poor aeration disrupted metabolism and reduced transpiration of herbaceous plants. Lorio, et al. (1972) showed that loblolly pines growing on flats had less fibrous root systems than those growing on low mounds.

Lack of aeration apparently affects the functioning of roots of other tree species in a similar manner. Shoulders (1976), working with slash pine seedlings, has demonstrated that reducing the oxygen level from 90 to 50 percent of equilibrium saturation with air reduced the root uptake of water, phosphorus, potassium, calcium, and magnesium but increased the uptake of nitrates.

Adaptation of lodgepole pines (*P. contorta* Dougl.) to poorly drained sites has been demonstrated. When subjected to waterlogging, roots of this species develop the ability to transport oxygen from the stem to root tissues (Philipson and Coutts 1978). This mechanism may also be present in loblolly pine. Field observations (unpublished) reveal that seedlings develop considerably more roots in fertilized, waterlogged soils, than in those waterlogged but not fertilized. Poor root development may also be related to calcium deficiencies and the imbalance in Ca:Mg ratios (Lyle and Adams 1971).

SOIL CHEMISTRY

Waterlogging and anaerobic environments of soils with prolonged high water tables cause dramatic changes in the properties of soil nutrients and their availability to plants (Patrick 1978). Oxygen, supplied by the soil or through the root, is required for normal nutrient uptake. Other chemical processes, however, may contribute equally to low uptake in poorly aerated soil.

One of the most striking effects is on pH of acidic soils. After prolonged waterlogging the pH becomes nearly neutral; it returns to its acid state as the soil dries (McKee 1970). This effect is cyclic with the rise and fall of the water table. Thus, the chemical compounds in waterlogged mineral soils are reduced, and the soil becomes anaerobic but not acid (fig. 1). The degree of reduction in the soil solution that takes place with waterlogging is expressed as the oxidation-reduction (redox) potential, in which positive values represent an aerated soil and negative values represent a waterlogged soil.

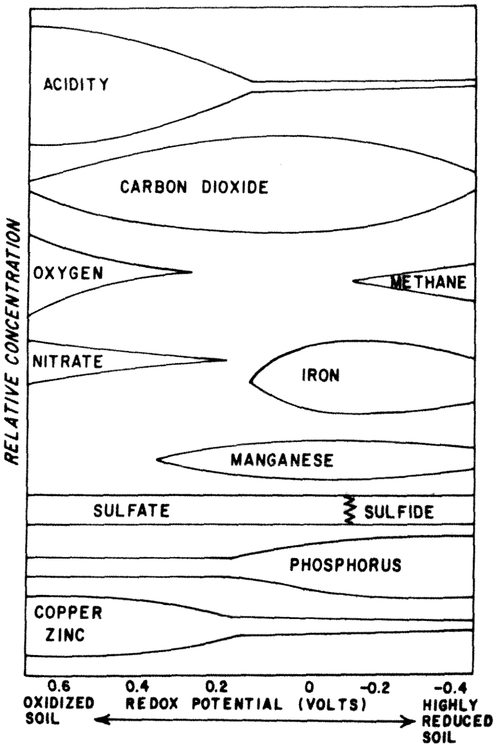

Figure 1.--Changes in relative concentrations of soil nutrients with waterlogging. Negative redox potentials indicate a high degree of waterlogging.

When the soil pores are saturated with water, only gases dissolved in water are present. Levels of oxygen are rapidly depleted by respiring microorganisms and roots of higher plants. Deficient aeration injures or kills the roots of many plants (Kramer 1951a). Simultaneously, levels of carbon dioxide increase until the soil solution is saturated with this gas (Ponnamperama 1972). This saturation is accompanied by a high content of carbonic acid and bicarbonates in the soil solution. As the soil becomes more anaerobic and reduced, the metabolic activity of organisms is lowered and the degree of carbon dioxide saturation diminishes but remains a dominant influence on the soil solution. A buildup of carbon dioxide can reduce water and mineral absorption (Kramer and Kozlowski 1960).

Nitrates, if present in the soil, are reduced soon after the oxygen is depleted, and the nitrogen is lost from the soil as a gas (Patrick 1978). Thus, it is not advisable to apply ammonium nitrate to poorly drained sites--the nitrogen will be lost rapidly to the atmosphere.

One of the most obvious effects of waterlogging is the reduction of iron and manganese to the ferrous and manganous forms, which are soluble (Patrick 1978). Both elements in their reduced forms act as cations similar to calcium and thereby help to increase soil pH under waterlogging.

When iron is solubilized in the ferrous form, it tends to bring phosphorus into solution. Thus, prolonged or repeated flooding and solubilization of phosphorus in forest soils may remove the nutrient from affected sites. When soils are reoxidized, the phosphorus may be tied up chemically in a less available form (McKee 1970). Furthermore, trees with waterlogged roots may lack the ability to use solubilized phosphorus efficiently (Kramer 1951b). However, such effects can be corrected by the application of phosphorus as a fertilizer. Why this is so is unknown; however, we speculate that the effects are possibly related to ion antagonisms or ion pairing.

The presence of large amounts of reduced manganese in waterlogged soil poses a problem in pine nutrition. However, it is uncertain whether manganese is directly toxic to trees or whether the ion upsets the nutrient balance. The buildup of the reduced metals could have effects on root systems similar to respiration inhibitors (Kramer 1951b). Higher nutrient levels may allow plants to develop alternate metabolic pathways which bypass the toxic metals. In either case, this condition can be corrected by the application of lime, which lowers the concentration of manganous ions in waterlogged soil.

Calcium and magnesium levels increase in waterlogged soil because of the high concentration of carbon dioxide. The exact effect of these reactions on mineral nutrition is ill-defined, but apparently leaching is increased, leading to a loss of exchangeable bases (McKee 1980). These reactions may account for the growth response to lime on poorly drained soils as reported by MacCarthy and Davey (1976) and Langdon and Hatchell (1977).

In waterlogged soils, trace elements such as copper and zinc decrease in concentration as they are precipitated as insoluble hydroxides, primarily because of the increase in pH. They also form insoluble sulfides in the presence of hydrogen sulfide. This gas, which is evident in the strong odor of swamp soils, is formed by the reduction of sulfate during prolonged waterlogging (Ponnamperama 1972). Drainage of waterlogged soils containing high concentrations of hydrogen sulfides (cat clays) results in extremely low pH values (<2) when the sulfides reoxidize to sulfuric acid. Prolonged waterlogging may also reduce the organic matter in soil to methane (swamp gas).

RELATIONSHIP OF SITE PRODUCTIVITY TO SOIL MOISTURE AND NUTRIENTS: A HYPOTHESIS

From the work reviewed, we have developed a working hypothesis on the relationship of site productivity to soil moisture and nutrients. Figure 2 illustrates this hypothesis. Briefly, site productivity is dependent on soil moisture and nutrient availability and their interactions. On very dry sites, nutrition is less critical than moisture because the latter is most limiting to growth. As moisture becomes more plentiful, nutrition plays a greater role in determining productivity. When a site becomes too wet, however, chemical reactions and lack of oxygen change the availability of nutrients, in some cases causing nutrient deficiencies of toxicities.

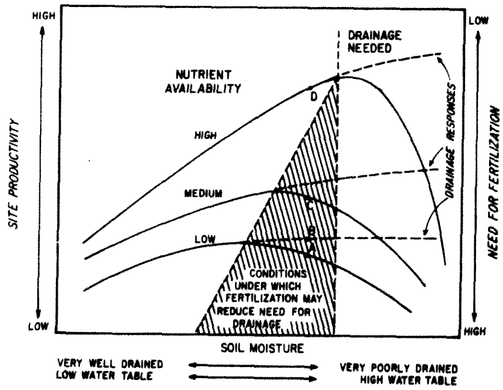

Figure 2.--Hypothesized relationship of site productivity to soil moisture and nutrients availability, the need for drainage and fertilization, and conditions under which fertilization may reduce the need for drainage.

Because of these relationships, we propose that fertilizing may greatly increase productivity of sites which are low in nutrients, poorly drained, and seasonally waterlogged (see shaded are in figure 2). For example, we hypothesize that draining a site with nutrient availability and moisture conditions as at point A in figure 2 would raise productivity to point B, but that fertilizing this same site to a medium or high nutrient level would raise productivity points to C or D without any drainage. We have demonstrated a similar response on a wet flat or savannah type (Langdon and Hatchell 1977). In a planting of several pine species on this unfertilized area, the best trees at age 11 were only about 12 feet tall, indicating that the site index was not more than 50 feet. Fertilization with phosphate and lime at age 11, and with nitrogen at age 14, converted the plots by age 17 to a site index of 85 feet. Admittedly, this is only one example, and it certainly does not indicate that our results are universally applicable. However, in discussing the work of the University of Florida's Forest Fertilization Cooperative, Bengtson (1971, p. 53) also observed that "appropriate fertilization may in the less waterlogged situations, obviate the need for drainage by stimulating early rapid growth of the pine stand." He pointed out that transpiration from such a stand "improves local drainage with ever-increasing benefits to root development and nutrient cycling."

Thus, our answer to the question of whether fertilization of loblolly or slash pine can reduce the need for drainage is a qualified "yes", especially if soil and foliar tests indicate deficiencies in phosphorus, calcium, nitrogen, or other nutrients. We realize that much more work is needed to test this working hypothesis; however, the evidence is strong enough for landowners to pilot-test this concept on wet sites that are apt to show response. Soils associated with such sites frequently have a dark surface horizon, and are classed as umbric aquults or groundwater spodsols. Mottling approaches the soil surface, and profile development is frequently weak and tongued. Water is normally present at or near the soil surface for several months each year. Ericaceous vegetation is usually more abundant here than on adjacent sites, and pines appear stunted and have short needles. Wet pine flats and savannahs are names often given to such sites.

The potential benefits to a landowner of fertilizing the sites in question would be to change low or nonproductive sites to ones of higher productivity at a relatively low cost with only minor soil disturbance and minimal use of heavy equipment.

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ESTIMATING FERTILIZER RESPONSE IN SITE-PREPARED PINE PLANTATIONS USING BASAL AREA AND SITE INDEX[1/]

Howard W. Duzan, Jr. and H. Lee Allen[2/]

Abstract.--Periodic growth models formulated for untreated and fertilized stands using basal area and site index as predictor variables represent a unique system for characterizing and quantifying response to nitrogen fertilization. Response was found to increase with increasing basal area and decrease with increasing site index. The equations produced provide a basis for selection of candidate stands for fertilization while giving better estimates of response needed for economic evaluation.

INTRODUCTION

The use of nitrogen fertilizers to enhance growth in Southern loblolly pine (Pinus taeda L.) plantations has steadily increased during the last few years. Results from fertilizer trials covering a wide range of soils and stand conditions in the South have encouraged many forest managers to consider nitrogen fertilization as a viable silvicultural tool. Although many trials have demonstrated substantial volume gains, some installations have indicated little or no advantage from nitrogen fertilization and in some cases negative responses have been reported. A method of characterizing those sites which are more responsive to nitrogen based on soil or stand parameters would greatly improve the gains from an operational fertilization program while providing better estimates for economic evaluation of proposed projects.

Efforts to diagnose sites which are responsive to nitrogen using soil or foliar variables alone have not produced acceptable results (Haines et al. 1976). Much of the problem has been our inability to determine the nitrogen fraction, in either soil or foliage, that best reflects nitrogen availability to the tree. Another consideration is the influence of stand characteristics on response, in particular, basal area per acre and site index at age 25. There are several reasons for looking at these two stand parameters. Basal area is a reflection of the needle biomass which is available to respond to fertilizer. Site index is a composite measure of the productivity of the stand, reflecting both soil physical and chemical properties as well as climate. Site index can also be viewed as an indicator of the severity of growth limiting deficiencies. If nitrogen is the limiting factor, site index should be related to a stand's responsiveness to nitrogen **application**.

Studies involving nitrogen fertilization of Douglas-fir (Pseudotsuga menziesii Franco) in the Pacific Northwest have shown that response is related to the stocking level of the stand at time of fertilization (Shumway and Atkinson 1978). Additional work with Douglas-fir suggests that response may be correlated with growth on the untreated stand (Anon. 1974). This point reemphasizes the importance of basal area and site index since periodic growth on any stand depends to a large extent on the growing stock and productivity of the site. In similar attempts to model response to nitrogen by Swedish researchers (Rosvall 1979), important independent variables were found to be site index, current untreated growth, age, nitrogen rate, latitude, and altitude.

A technique is described in this paper for predicting volume response to nitrogen fertilization in established loblolly pine plantations using basal area per acre and site index. The utility of any response model using these measures as independent variables is enhanced by the direct application of the model to existing inventory systems. Selection of candidate sites and evaluation of gains from a fertilization program can be accomplished with little effort. More precise diagnostic techniques

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for soil and foliar nitrogen levels can be incorporated into an existing basal area-site index model to more accurately estimate nitrogen needs for individual stands as they become available.

PLOT DATA

Data selected for fitting the proposed model represent a subset of fertilizer trials established in 1971-73 by Forest Industry members of the North Carolina State Forest Fertilization Cooperative. Control plots and plots fertilized with 100 pounds of elemental nitrogen (as ammonium nitrate) per acre were chosen from 37 trials. Installations were selected to cover a wide range of stand conditions on a variety of soil types across the South. Further constraints included selection of stands which had been site-prepared and which had foliar phosphorus levels of .1% or greater. The range of stand conditions for selected trials is summarized in table 1. Measurements were made initially and after five years. Per acre volumes were calculated using a total stem, outside-bark equation for individual trees (Smalley and Bower 1968). Gross volume growth estimates were calculated using all trees and do not include losses to mortality.

Table 1.--Summary of stand conditions for trials included in the data set (37 trials with paired treatments, total observations = 74).

Variable	Mean	Std.Dev.	Range
Age (yrs)	12	4	5-18
Site index (25 yr,ft)	63	10	45-90
Stems/ac.	754	163	397-1165
BA/ac. (ft^3)	86	52	6-174
Foliar N (%)	1.16	.13	.88-1.39
Foliar P (%)	.14	.04	.10-.20

A MODELING APPORACH

Modeling of fertilizer response can be accomplished through several avenues. The traditional method is to calculate periodic volume response (fertilized minus control) for each trial and relate this measure to the initial stand parameters using regression techniques. A problem arises in that fertilized and control plots may or may not be comparable due to differences in stand characteristics prior to treatment. Covariance analysis can be applied using this method to adjust for initial conditions prior to calculating response. Another approach to assessing response is to determine the impact of nitrogen fertilization on the growth trends of fertilized stands.

Five-year volume growth on the control plots was related to initial basal area and site index using a growth model which was developed from biological principles. Scatter diagrams of raw data were used to substantiate the growth model used. Fertilized plots were included in the model and dummy variables were used to statistically test for changes in the coefficients of the untreated model which resulted from inclusion of the fertilized plots. All possible combinations of treatment influence on the model were examined. Coefficients for the basal area and basal area x site index terms in the denominator of the model were found to be significantly altered by application of nitrogen fertilizer. Other coefficients in the model were not significantly altered. The equation produced using this technique provides a method for determining how nitrogen fertilizer changes the periodic growth pattern on treated stands. In addition, estimates of periodic volume growth for both treated and untreated stands of known basal area and site index can be calculated. The combined model for both untreated and fertilized stands is:

$$\text{Growth} = (52.61087 + BA)/(0.124105 + 0.0003557*BA - 0.001027*SITE - 0.00000006*BA*SITE - 0.0005146*BA*T_1 + 0.00000601*BA*SITE*T_1)$$

Where: Growth = 5-year gross volume increment (cu.ft/acre)
BA = initial basal area (sq.ft/acre)
SITE = 25-year site index (ft)
T_1 = treatment effect,
T_1 = 0 for untreated
T_1 = 1 if fertilized with N100

R^2 for combined model = .73
Standard Error of mean = 31 cu.ft/acre.

Analysis of sequential sums of squares for the combined growth model revealed that basal area accounted for 56% of the total corrected variation, inclusion of site index accounted for an additional 11%, and the treatment effect produced a further reduction of 6%. All included effects were statistically significant ($\alpha = .05$).

Growth curves developed from the above equation for untreated and fertilized stands at two site index levels are illustrated in figure 1. Note the basic shape of the periodic growth curves under untreated conditions and the changes which occur when nitrogen is applied. Estimates of response to nitrogen over control derived from the composite growth equation are presented in table 2 for a range of basal areas and two site indices.

DISCUSSION AND CONCLUSIONS

The data, illustrated in figure 2 and presented in table 2, demonstrate the relationships between response and stand parameters over the range normally found in managed plantations. The most obvious trends are decreasing response as site index increases and increasing response as basal area increases. In order to explain these results, we must consider first the attributes of the data set used to fit this model. Phosphorus-deficient sites and poorly-drained or excessively drained sites which are major factors contributing to poor site quality in much of the South were not included.

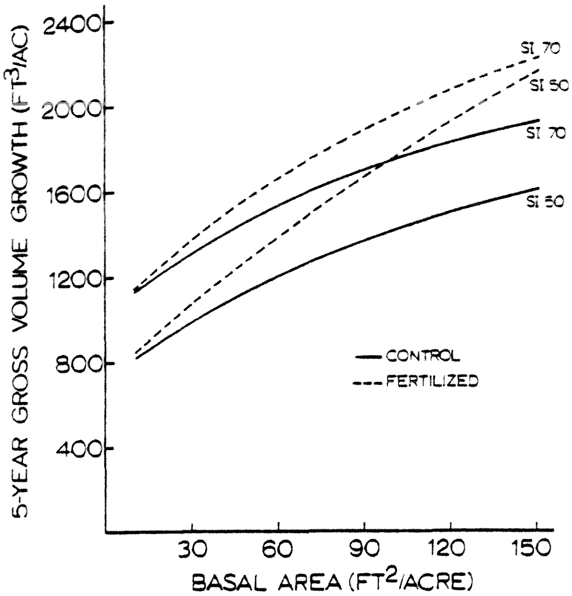

Figure 1.--Five-year periodic growth predictions for untreated and fertilized stands (100 lbs N/ac) using basal area at two levels of site index.

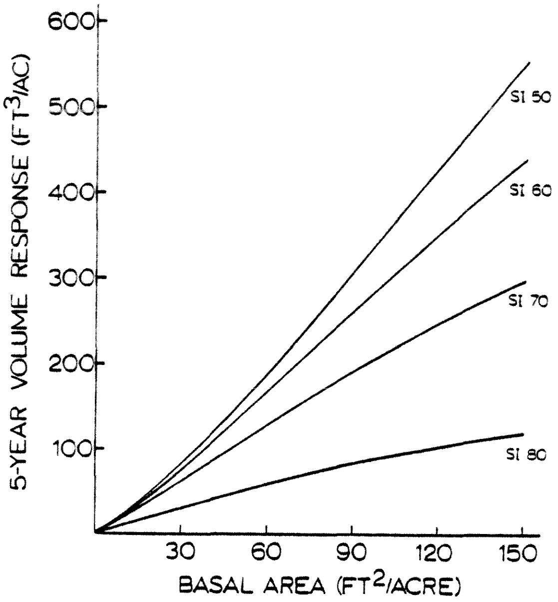

Figure 2.--Relationship of basal area and site index to five-year volume increment over control for stands fertilized with nitrogen. (Based on fitted growth equations.)

Table 2.--Five-year gross volume response (cu.ft/acre) with application of 100 pounds of elemental nitrogen.

Basal Area	--------Site Index (ft)-------- 50	60	70	80
(sq.ft/acre)				
10	24	23	19	10
30	83	76	62	31
50	153	136	106	50
70	229	199	149	68
90	309	261	191	84
110	390	323	230	98
130	472	383	266	110
150	554	440	299	121
170	634	496	331	131

With removal of these factors as primary influences on site productivity, the data suggest that the limiting factor may be nitrogen. The simple correlation between site index and foliar nitrogen percent (r = .48) was positive and statistically significant (α = .01). We speculate that high site indices are associated with areas having a favorable nitrogen status, thereby providing a reasonable explanation for lower responses to nitrogen on stands with higher site index.

Poor response to nitrogen on stands of low basal area (10-30 sq.ft/acre) is to be expected. The lack of an adequate growth base to give quantitative expression to the response, coupled with uptake of nitrogen by competing vegetation, make fertilization of very young stands inefficient. As stands become more developed and approach crown closure (50-90 sq.ft. of basal area), a larger response to nitrogen can be anticipated. Response continues to increase according to this model, as basal areas approach 150 square feet per acre. Biologically, we might expect that as stands become fully to overly-stocked, response to nitrogen, measured as gross volume growth per acre, would level off or possibly decrease, since crown surface area would be at a maximum (Tamm 1979). This trend cannot be substantiated using the fitted model since very few of the site-prepared stands were heavily enough stocked to determine if response in fact declines at higher basal areas.

Extrapolation beyond the ranges of the original data set may produce erroneous estimates of response. This limitation applies not only to basal area and site index but other parameters as well. Population conditions which must be satisfied include stands which are:

1) site-prepared loblolly pine plantations,
2) not P-deficient or have had phosphorus applied prior to planting,
3) naturally well drained or were artificially drained prior to planting,
4) exclusive of excessively drained, sandy sites.

The relationship between site index and response to fertilizer is particularly sensitive to the population of stands used to fit the model. In the case of this model, the data set used was quite restricted, being taken from stands on non P-deficient sites exhibiting a narrow range of drainage classes. The result was a negative relationship between site index and response probably reflecting a dominant influence of N status on site index for this population. A similar model, being published in the Southern Journal of Applied Forestry (Duzan et al. 1980), and fit using older, essentially old-field stands covering a wide range of soil P and drainage conditions, gave a positive relationship between site index and response. This probably reflects the restrictive effect of extreme drainage conditions and P-deficiency on N response in the low site index range. This apparent difference does not reduce the validity of either model, but rather emphasizes the importance of selection of the appropriate model for various stand conditions.

Two further points in regard to the use of the presented growth model should be considered. First, incremental response from nitrogen fertilizer is estimated over a five-year growth period. Some additional gains may occur after five years, particularly in young, low basal area stands. Secondly, the recommended optimum application rate for nitrogen is 150 pounds per acre which it is estimated will increase response approximately 15% over those estimates in table 2 (NCSFFC 1980).

Although this data set is quite restricted, it does represent a large acreage of plantations in the South. As future regeneration efforts concentrate on cut-over sites and corrections for phosphorus deficiencies and poor drainage improve productivity on many areas, the utility of this model for characterizing stands responsive to nitrogen will increase.

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NITROGEN FERTILIZATION OF ESTABLISHED LOBLOLLY PINE STANDS:

A FLEXIBLE SILVICULTURAL TECHNIQUE[1/]

R. Ballard[2/]

Abstract.--Results are presented which resolve many of the uncertainties regarding suitable nitrogen (N) fertilizer sources and effective rates and times of application for fertilizing loblolly pine plantations. Recent developments in fertilizer response prediction technology are covered. The potential for using N fertilization to manipulate fiber supply and size classes of timber is discussed.

INTRODUCTION

Nitrogen (N) fertilization of established stands is a well accepted silvicultural technique in the Pacific Northwest (PNW) but its acceptance in the South has been much slower. Currently about 300,000 acres are fertilized with N annually in the PNW while only ca 60,000 acres are fertilized annually in the South (Bengtson 1979) and most of this is on one ownership. This is not an indication that responses to N are greater or more frequent in Douglas-fir than in the Southern pine forests: evidence indicates that average responses over a range of sites in both regions are remarkably similar (Miller & Fight 1979; Haines _et al_ 1979). There appear to be two major factors retarding operational use of N fertilizers in established Southern pine plantations. These I will label as the P-resonse syndrome and the technology gap.

ACCEPTANCE PROBLEM

P-Response Syndrome

The South is unfortunate in more ways than one in having some extremely P-deficient forest soils in the Lower Coastal Plain region. Not only do resources have to be committed to ameliorate the problem on these soils but the type of response achieved has unfortunately set standards of acceptance among many forest managers for fertilizer response. Phosphorus deficiency is very much a problem of young developing plants and its correction invariably produces visually spectactular responses. We have all seen these responses in the field or in publications (Pritchett & Smith 1974) where P fertilization makes the difference between having or not having a plantation.

Based on results from an extensive series of trials in loblolly pine plantations throughout the South, it is apparent that the productivity of most plantations are limited to some extent by N deficiencies (table 1). The responses obtained, which average about 2 cords/acre over a 4 to 5 year period after fertilization, but range up to about 8 cords per acre, are commercially viable in many cases. However responses of 2 to 5 cds/acre are difficult to "see" in plantations with 15 to 30 cds/acre of standing timber. These non-visual responses in apparently healthy plantations are difficult to sell to managers accustomed to thinking of fertilization as an all or nothing remedial measure. The challenge in the South today is to sell N fertilization as an investment opportunity, not as a remedial measure.

Technology Gap

Even where forest managers can be sold on the benefits and opportunities of N fertilization, they still need and demand certain information before going operational. Because most managers have only limited financial resources at their

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Table 1.--Average volume gains, by physiographic regions, for loblolly pine plantations fertilized with either 150 or 100 lbs N per acre

Treatment	Piedmont	Upper Coastal Plain	Lower Coastal Plain	All Sites	Range
	------------------(4-yr cu.ft/acre gain)------------------				
150N[1]	189	157	235	205	-44 to 552
	(24) [3]	*(6)*	*(22)*	*(52)*	
	------------------(5-yr cu.ft/acre gain)------------------				
100N[2]	219	155	126	166	-229 to 802
	(47)	*(43)*	*(53)*	*(142)*	

[1] Any P deficiency corrected by fertilization. Plantations had an average age of 12.3 yrs with a range from 2 to 21 years; initial basal area averaged 88 sq. ft/acre with a range of 0 to 291 sq.ft/acre.

[2] Any P-deficiency not corrected. Plantations had an average age of 12 yrs with a range from 2 to 35 years; initial basal area averaged 102 sq.ft/acre with a range of 0 to 223 sq.ft/acre.

[3] Values in parenthesis indicate number of fertilizer trials.

disposal their first requirement is to be able to identify sites where the largest and most profitable responses will be obtained from N fertilization. In addition he needs to know what source of fertilizer to apply, when to apply it and the most economical rate to apply. Lack of suitably accurate techniques for predicting quantitative responses to N fertilization and uncertainty over effective fertilizer sources, rates and times of application has undoubtedly contributed to the slow acceptance of operational N fertilization in the South.

Recent information generated from the extensive number of N fertilizer trials installed by Forestry Industry members of the North Carolina State Forest Fertilization Cooperative (NCSFFC) goes a considerable way towards resolving many of the above uncertainties.

STATE OF THE ART

Prediction of Response

Attempts to predict N fertilizer response in forest plantations have in the past centered on measurements of N in the soil or plant tissues. These traditional methods have largely proved unsuccessful at predicting the quantitative response to N fertilization (Ballard 1980).

As response information became available from NCSFFC N-fertilizer trials covering a wide range of both stand and soil conditions, it became apparent that the quantitative response was associated more with stage of stand development than soil variables. This is perhaps not surprising in view of the ubiquitous nature of N deficiencies throughout the loblolly pine range and the obvious role the stage of stand development plays in setting growth limits.

Models have been developed using basal area and site index, for predicting the magnitude of N fertilizer response in older, mainly old-field loblolly pine plantations (Duzan et al 1981; fig. 1 and for younger, site prepared plantations (Duzan and Allen 1980). These models are compatible with most inventory systems which enables site selection for N fertilization without additional field sampling and also provides the opportunity for evaluating various N fertilization strategies in relation to ownerships production and product goals. While these models are effective at predicting the average response to be expected from N fertilization of various stand types, predictions for specific sites are subject to quite a wide margin of error. Theoretically a better predictio of response magnitude should be possible from a model which identifies sites according to both their N status and stand variables that control the potential periodic increment of the stand over a 5 to 7 year period following fertilization. Enhanced growth rates in N-fertilized forest plantations typically persist for only 5 to 7 years (Ballard 1981a). Work is underway within NCSFFC to develop such a model.

With the large value differentials between pulpwood and logs used for solid wood products, most loblolly pine stands harvested are now merchandized according to diameter classes. Consequently, most forest managers would like to know more than just the total volume response from fertilizing a stand. For the purpose of determining profitability, they would also like to know the distribution of the volume response among diameter or merchantability classes. This type of information is obtainable using an individual tree

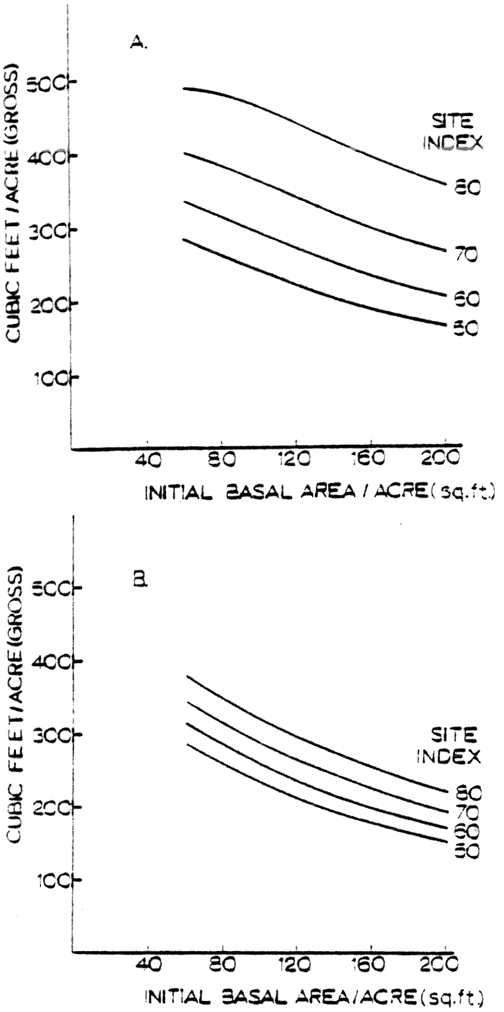

Figure 1.--Influence of initial basal area and site index (25 yr) on 5-year gross volume response from fertilization of loblolly pine plantations with 100 lbs N + 50 lbs P/acre in the Lower Coastal Plain (A) and Piedmont (B) regions (Duzan et al. 1981).

analysis approach: using regressions of volume growth on diameter class for both fertilized and unfertilized stands, the fertilizer response in either initial or final diameter classes can be determined (fig. 2). We have identified certain trends in response distribution patterns which appear to be related to the stage of stand development (Rogers 1978): in young, open grown stands response tends to occur equally among the diameter classes; in stands exhibiting some crown competition response tends to be greater in larger diameter classes; and in severely overstocked stands response in larger diameter classes tends to be off-set by suppression of growth in smaller diameter classes. Our objectives now are to define those stand and site conditions which show common trends and to mesh response distribution predictions with our gross volume prediction models.

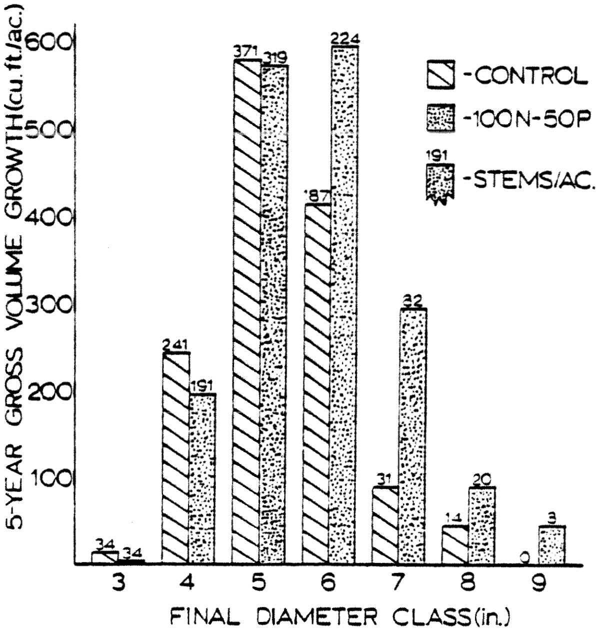

Figure 2.--Five-year volume growth per acre by final diameter class following fertilization of a 9-year-old loblolly pine plantation with 100 lbs N + 50 lbs P per acre.

Fertilizer Sources

In forestry, the choice of a N fertilizer is essentially between ammonium nitrate (AN) and urea (U). Other N sources are available, but high costs per unit of N or low analysis values, which increase handling and application charges, tend to preclude their use for operational fertilization of forest stands (Bengtson 1976).

A comparison of AN and U, applied at 150 lbs N/acre over a wide range of site and stand conditions throughout the South, revealed no significant differences in effectiveness of these two sources Ballard, 1981b): differences in response between the two sources were small in relation to the magnitude of the response to N (table 2). Either source is acceptable for fertilization of loblolly pine plantations and the choice should rest on such considerations as local availability, price, and cost of application.

Timing of Application

Seasonal--In the trial series comparing AN and U, these N-fertilizer sources were applied at 3 times of the year. Results showed significant differences in response between application dates at 3 out of the 11 sites (table 2). The difference at all 3 sites was associated with a significantly poorer response from the summer (June) application of both N sources (Ballard 1981b). Soil and stand conditions appear to be unrelated to the effectiveness of summer applications: it is suspected that the higher probability during summer of heavy rains,

Table 2.--Main effects of nitrogen fertilizer sources and time of application on 4-year volume response in loblolly pine plantations.

Trial no.[1]	Source[2]			Time of Application[3]		
	AN	U	AN-U	Feb.	June	Oct.
	(cu.ft/acre)					
1	15	84	-69	33	107	7
4	168	169	-1	162	180	164
6	340	285	65	331	287	317
7	522	497	25	549a	425b	554a
9 (T)	283	308	-25	330	248	308
9 (UT)	191	155	36	106	-	240
11	235	314	-79	345a	165b	313a
15	169	171	-2	167	173	-
16	125	125	0	123	140	113
19	130	81	49	158a	12b	147a
24	178	118	160	139	195	110
Avg.	214	210	4	222	193	227

1/ NCSFFC trial code. For details of individual trial site and stand conditions see Ballard (1981b).

2/ Ammonium nitrate (AN) and urea (U).

3/ Treatments within rows not followed by a common letter differ significantly ($P < 0.05$). Treatment differences non significant in rows without letters.

capable of leaching N from both sources, accounts for the apparent randomness of the sites showing an inferior response to summer applications.

It is recommended that AN and U be applied in either spring or autumn. Our knowledge of N behavior in soils also leads us to recommend that even within these seasons, applications should be avoided when 1) the ground is water-logged, 2) long, dry hot spells are forecast, and 3) torrential down-pours are likely within a few days of application. Although we have not tested winter applications, theoretical considerations suggest that N fertilizer effectiveness might be reduced by application during this season, particularly in cold areas subject to snow accumulations and on wet sites, due to high leaching and denitrification losses.

Stage of Stand Development--Our fertilizer response prediction models indicate as in figure 1 that periodic (5 years) response increment is related to basal area. The precise nature of the relationship is not clear in the middle range of basal areas but it is clear that much smaller quantitative responses are obtained if N fertilizer is applied when the stand is either very understocked (< 20 sq.ft/acre basal area) or severely overstocked (> 160 sq.ft/acre basal area.)

Optimum Rates of Application

Trials designed to determine optimum N rates for fertilizing loblolly pine plantations have shown optimum rates to be fairly independent of site and stand conditions (Ballard, 1981a). For 11 out of 17 N-rate studies which showed a significant response to N fertilization, the average N rate which maximized volume response (biologic optimum) was 200 lbs N/acre (table 3). Based on assumed pulpwood and sawlog stumpages of \$0.20 and \$0.70 per cu.ft., respectively, average economic optimum N-rates for capture of the total response on either pulp or sawlogs were calculated to be 57 and 152 lbs N/acre, respectively. The standard error for the average sawlog optimum was only ±10 lbs N/acre. Because of the

Table 3.--Estimated optimum N application rates and their associated volume responses for loblolly pine plantations.

Trial[1] No	Optimum N application rate			Volume response		
	Economic					
	Pulpwood	Sawlog	Biologic	Pulpwood	Sawlog	Biologic
	------------(lbs N/ac)---------			-----------(cu.ft/ac)---------		
21	13	134	182	27	183	195
51[2]	84	219	354	194	397	463
62	82	128	147	267	327	333
81[2]	0	172	256	0	199	224
82	64	156	200	245	427	502
111	94	168	198	274	368	378
151	64	156	200	186	357	380
152	100	145	163	362	420	425
161[2]	20	183	248	42	252	271
191	42	105	131	104	185	193
231	61	105	122	184	240	245
Avg.	57	152	200	171	309	328

[1] NCSFFC trial code. For details of individual trial site and stand conditions see Ballard (1981a).

[2] Based on four-year response information. All other trials based on five-year response information.

relatively small variation about average optimum rates, the difficulty of uniformly applying fertilizer under operational conditions and the typically large within site variability of most forest management units, standarized application rates are recommended for specific silvicultural regimes.

Unknowns

Fertilization has been incriminated in increasing the incidence of diseases such as fusiform rust and pitch canker and the degree of damage from snow and ice. We do have evidence (Kane 1980) that N fertilization of loblolly pine plantations greater than 2 years of age does not increase fusiform infection rates or associated damage. Effects on the incidence of other diseases and pests attacks are largely unknown.

In very few cases do we have any evidence to support the contention that N fertilization increases the degree of damage from ice and snow. Out of the several hundred NCSFFC fertilizer trials throughout the South, we have only two trials in which the degree of ice damage has been obviously related to N fertilization.

The interactions between N fertilization and other silvicultural operations in loblolly pine plantations, particularly thinning and prescribed burning, are not well understood. While we have found that on the average thinned stands of loblolly pine respond somewhat more than unthinned stands (table 4), it is not a consistent trend. The nature of this interaction is examined in another paper at this Symposium (Ballard, et al. 1980).

Table 4.--Average 4-year volume increment from thinning x N fertilizer studies in twelve loblolly pine plantations.[1]

Treatment	4-year volume growth	
	Gross	Net
	-----(cu.ft/acre)------	
Unthinned	1478	1197
Unthinned + N Fert	1635	1321
Fert gain	157	124
Thinned	1156	1082
Thinned + N Fert	1353	1266
Fert gain	197	184

[1] Plantation age averaged 15.6 years with a range from 11 to 20 years; basal area in the unthinned areas averaged 156 sq.ft/acre with a range of 97 to 191 sq.ft/acre, while that in the thinned areas averaged 97 sq.ft/acre with a range of 80 to 120 sq.ft/acre. Thinning was done selectively from below. Fertilizer applied at 150 lbs. N/acre.

Nitrogen-fertilization technology has undoubtedly now reached the point where operational N fertilization can realistically be included among silvicultural options available to forest managers. However, the technology is still in a very early development stage. Refinements in predictive techniques, methods and frequency of application and an improved understanding of interactions with other silvicultural operations and long-term residual effects could further enhance its value as a silvicultural tool.

SILVICULTURAL IMPLICATIONS

Many of the major timber producing areas in the world, including the Southern United States, are facing a timber supply problem due to an imbalance in age and size classes (Zobel, 1980). The problem is associated with an abundance of young sub-merchantable plantations, a rapidly declining "old-growth" resource and an inadequate acreage of intermediate age (size) timber. The general responsiveness of loblolly pine plantations in the South to N fertilization offers a number of opportunities for reducing the impact of this imbalance on both fiber supply and material suitable for solid wood products.

Fiber Supply

Early utilization of young stands, usually by partial cutting (thinning), is a possible way of reducing the age-gap problem. However, as thinning usually reduces the amount of fiber produced per acre over normal loblolly pine rotation lengths (25-35 years), critics point out that thinning may serve only to delay the problem.

Nitrogen fertilization provides two major opportunities for reducing the age-gap problem.

1. Fertilization of young stands 5 to 7 years prior to thinning, when basal area is in the optimum range of response, would enable either earlier thinning or greater volume removal at a predetermined thinning age.

2. Fertilization of thinned stands increases the rate of growth and acts to offset the impact of growing stock removal on fiber production. Our data (table 4) show that average net periodic volume growth in fertilized and thinned stands exceeded that in unthinned stands.

Assuming no selection for responsiveness to N fertilization, the average response from N fertilization (150 lbs N/acre) of a young plantation with 60-80 sq.ft/acre of basal area would be approximately 3 cords per acre. We anticipate a response of similar magnitude would be obtained from refertilization following thinning. There is thus a potential, under such a silvicultural regime, for increasing the fiber supply from loblolly pine plantations by an average of 6 cords per acre over a rotation.

Size Class Distribution

Many of the options available for accentuating growth on individual stems—use of genetically improved stock, wide spacing at planting, intensive site preparation—are long term in nature and thus of little use in resolving the immediate size-gap problem. Thinning is the technique most frequently used to provide relatively short-term exploitable gains in individual stem growth. Nitrogen fertilization can also be considered among the options for providing relatively short-term improvements in the supply of larger-sized timber. In this respect, fertilization can be exploited under a number of circumstances.

1. Nitrogen fertilization in conjunction with thinning not only provides more volume gain than fertilization of unthinned stands (table 4), but this volume gain goes onto fewer, larger stems. Many stands which are commercially thinnable by today's standards of minimum extraction volumes and average diameters are, due to close planting, overstocked. In such stands the response to thinning can be minimal due to either severe crown suppression or because the residual crop component has already established dominance. Our data (Ballard *et al*. 1980) would tend to indicate that fertilization of such stands after thinning will produce a response even though there is no response to thinning per se or to fertilization of the unthinned stand.

2. Many intermediate and older age pine stands in the South are so grossly overstocked, that not only will there be little response to thinning but thinning places such stands in jeopardy from ice, snow, and wind damage. The development of these stands to timber of merchantable size is slow. Our experience from fertilizing such stands shows that fertilization can produce a quite pronounced shift in diameter class distribution. In a case study it was shown that an overstocked stand which showed no net gain in volume from fertilization increased significantly in value due to a stimulation in growth of larger trees at the expense of smaller trees (Rogers 1978). Nitrogen fertilization offers an opportunity to speed up the development of overstocked stands into a merchantable condition.

By way of conclusion it is emphasized that N fertilization of loblolly pine stands is not an obligatory management practice—in most cases stands will grow and remain healthy without it. However it does offer an investment opportunity to produce more fiber and to help resolve some supply problems.

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UNDERSTORY BIOMASS FOR ENERGY FUEL[1]

Timothy T. Ku, James B. Baker, Charles R. Blinn
and Richard A. Williams[2]

Abstract.--A cooperative study funded by the Department of Energy was initiated in 1979 to evaluate the potential use of understory vegetation in uneven-aged southern pine forests as an energy source. Objectives are to characterize understory vegetation, determine its recovery rate from harvest and impact of harvests on site. Preliminary results indicate an average yield of 24.41 T/ha.

INTRODUCTION

The world wide demand on energy resources has resulted in accelerated research activities in renewable energy technologies including bomass energy sources. The vast area of commercial timberlands in southern United States in conjunction with its favorable environmental and socio-economical conditions provide the region with an ideal setting for investigating renewable energy resources from forest biomass.

In order to increase timber production, considerable effort has been expended to reduce competition from the unmerchantable and often unwanted understory vegetation. In view of the increasing demand on energy, the use of this renewable understory vegetation as a possible source of fuel suddenly becomes highly appealing, and a cooperative study between the Department of Forestry, University of Arkansas at Monticello, the USDA-Forest Service and Georgia-Pacific Corporation was initiated and funded by the Department of Energy in 1979.

GOALS AND OBJECTIVES

A systematic approach to the problem of using understory biomass as an energy source would include:

(1) characterization and feasibility of the resource,
(2) harvest and transport of the resource,
(3) conversion and utilization of the resource,
(4) long term effect of periodic harvests of the resource on site quality.

Due to energy shortages within the last several years, many forest industries have resorted to solid fuel boilers and generating systems in their physical plants. These plants are currently relying, at least partially, on logging and mill residues and can be easily converted to utilize the understory biomass. Proto-type mobile harvester-chippers have been under development during the past decade to be more efficient in harvesting and collecting the small trees and logging residues for fiber. Such systems can easily be adapted to collect and transport the understory biomass to concentration locations. These developments will eventually solve phases (2) and (3) of the problem.

This study concentrates primarily on phase (1) and to a very limited extent, obtain baseline information relating to long term impact in phase (4). If understory vegetation is a feasible energy resource which can be harvested periodically, then the use of this resource would not only supplement the increasing demand on energy fuel but would also increase the growth of overstory crop trees, lessen the need for brush control, and reduce site preparation and timber stand improvement costs.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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Table 1.--Understory Biomass (T/ha) by Site Classes

GOOD SITE				POOR SITE			
Pine		Pine-Hardwood		Pine		Pine-Hardwood	
High Density	Low Density	High Density	Low Density	High Density	Low Density	High Density	Low Density
SUMMER HARVEST							
32.84	26.34	10.29	26.70	48.26	20.49	20.49	50.42
19.23	9.21	15.31	38.38	25.89	47.21	18.43	18.38
19.64	19.70	22.73	20.44	34.84	34.81	29.16	16.99
23.90	18.43	16.12	28.51	36.34	34.16	22.69	28.60
21.16		22.33		35.26		25.65	
21.74*				30.46*			
26.12							
WINTER HARVEST							
22.42	12.76	11.81	29.16	50.93	13.76	10.13	31.99
20.16	14.59	18.70	18.18	21.92	31.00	14.93	23.25
30.40	16.59	28.18	25.62	28.36	23.99	13.38	32.55
24.32	14.64	19.57	24.32	33.74	22.91	12.82	29.25
19.48		21.95		28.34		21.03	
20.71				24.68			
22.69							
AVERAGE							
27.62	19.55	11.05	27.93	49.61	17.13	15.31	41.20
19.70	11.90	17.01	28.27	23.92	39.10	16.68	20.83
25.02	18.16	25.47	23.02	31.59	29.41	21.27	24.77
24.12	16.54	17.84	26.41	35.04	28.56	17.75	28.94
20.33		22.13		31.81		23.36	
21.22*				27.60*			
24.41							

*$P < 0.10$

The short-term objectives of this study is to characterize and quantify the understory biomass in uneven-aged, natural, southern pine stands in south Arkansas and north Louisiana. Long term objectives are to determine (1) the recovery rate of the understory biomass after harvest and (2) the effects of periodic harvests of understory biomass on site quality.

METHODS

Forty 0.2 hectare main plots from a factorial design with 3 replications of two forest types--pine and pine-hardwood, two stand density classes --high and low, and two site classes--good and poor was established in a 14-county area in south Arkansas and north Louisiana. During 1979-80, three replications of 24 plots were established; the remaining 2 replications of 16 plots were established in 1980-81. This paper will report the preliminary results from the 24 plots established in 1979-80. Within each main plot, all woody vegetation less than 14 cm dbh was inventoried from 18, 3.05M x 3.05M subplots. Nine subplots were harvested and chipped in late summer during full foliage and nine in winter.

Fresh weight of the chipped material from each subplot was obtained in the field. Subsamples were subsequently taken and dried at 70°C in a walk-in kiln. After drying, weighing, and determining plot dry weights, the subsamples were further pulverized in a Wiley mill and used for chemical analysis of N, P, K, Ca and Mg contents. These nutrient data are used to quantify nutrient removal from harvest.

Soil samples were collected immediately after each harvest at 7.5 and 15 cm depths from each subplot. Nutrient contents (N, P, K, Ca, Mg) will be analyzed and used with biomass nutrient data to correlate the impact of periodic harvest on nutrient reserves.

RESULTS AND DISCUSSION

Preliminary results derived from quantitative data obtained from 24 plots at the end of the first year indicated the following significant findings:

Understory Biomass Production

The average understory biomass across all 8 stand-and-site conditions was 24.41 ± 11.37 dry metric tons per hectare (T/ha) with a range of 10.13 to 50.93 T/ha (Table 1). At a conservative guess of a 10-year harvesting cycle, this chippable understory biomass would amount to nearly 2.5 T/ha/yr., which is above the commercially operable quantity for some industries under present standards.

Although the average summer harvest of 26.12 T/ha was slightly higher than the winter average of 22.69 T/ha as one would expect, analysis of variance indicated this difference was not statistically significant. This is probably due to the high variability in composition, density and site conditions among plots, and to a lesser degree, the presence of conifers and broadleaf evergreens.

Poor sites produced more understory biomass (27.60 T/ha) than good sites (21.22 T/ha) ($P<0.10$) for the average of two harvest (Table 1). Yields from the Summer harvest on poor sites was also significantly ($P<0.10$) greater. The higher understory biomass obtained from poor sites may possibly be explained by the fact that more large understory stems (5 to 12.5 cm dbh) occupied poor sites than good sites (Table 2). This resulted from either past management practices and/or less shading by overstory trees. There are generally smaller numbers of large overstory trees on poor sites,perhaps reflecting the principle of site productivity.

Table 2.--Number of Stems by Size and Site Classes

	DBH	Good Sites	Poor Sites
	(cm)	------ Stems/ha	--------
Understory			
	5.0	1863	2143
	12.5	204	304
Subtotal		2067	2447
Overstory	20.0	116	165
	27.5	66	65
	35.0	39	36
	42.5	23	16
	50.0	12	5
	57.5	2	2
Subtotal		258	289
Total		2325	2736

Understory Biomass Composition

A Dominance-Index was derived to rank the understory biomass components by using a model:

$$DI = 1.66667 + 0.04510\ \Sigma(D_i) + 0.04336\ \Sigma(D_i^2)$$

where N is the number of stems for a given species, D_i is the dbh of stem i for a given species, all on a per unit area basis. The model was slightly modified from Chisman and Schumacher (1940).[3/]

Based on the mean Dominance-Index, the 10 most dominant understory woody species in descending order are: red oaks, red maple, winged elm, dogwood, sweetgum, pines, white oaks, French mulberry, blackgum, and hickories. Hopefully, some form of a Dominance-Weight-Index may be developed so that the index will correlate with understory biomass of a stand.

[3/] Chisman, H. H., and F. X. Schumacher. 1940. On the tree-area ratio and certain of its applications. Jour. For. 38:311-317.

Table 3.--Biomass and Nutrient Contents in Understory Vegetation (Kg/ha) by Site Classes-Summer Harvest.

Item	Good Site	Poor Site	Mean
Biomass	20,740*	30,460*	25,600
N	90.6**	109.8**	100.2
P	11.9*	12.6*	12.2
K	64.9	78.1	71.5
Ca	138.7	169.6	154.2
Mg	14.5	18.6	16.6

** $P < 0.05$
* $P < 0.10$

Nutrient Content in the Understory Biomass

The 216 biomass samples collected from the summer harvest (9 subplots in each of 24 main plots) were analyzed for N, P, K, Ca and Mg contents. The mean nutrient concentrations (%) of all samples were: N, 0.439; P, 0.059; K, 0.323; Ca, 0.688, and Mg; 0.081. Average nutrient removal from all summer harvested plots in Kg/ha were: N, 100.2; P, 12.2; K, 71.5; Ca, 154.1 and Mg, 16.5. Analysis of variance indicated the nutrient removal was significantly higher in nitrogen ($P<0.05$) and phosphorus ($P<0.10$) from poor sites than from good sites (Table 3), primarily a reflection of biomass differentials. Further analysis will be pursued when data from summer- and winter-harvest of all plots becomes available.

CONCLUSION

Preliminary analysis of available data indicates there is a sufficient amount of understory woody biomass in natural, southern pine forests that can be possibly harvested for energy or even fiber use. However, the recovery time required between harvests must be determined to assess biomass productivity (T/ha/yr). The nutrient concentrations of the understory biomass and the soil are also needed to quantify nutrient removal from harvest and to estimate changes of nutrient reserve from repeated harvests.

If periodic harvests of understory biomass becomes a reality, in addition to providing a renewable energy resource the harvests will also provide an inexpensive silvicultural treatment for controlling competing hardwoods in pine stands.

INVENTORYING WINDROWED LOGGING RESIDUES[1/]

W. Henry McNab[2/]

Abstract.--A set of user-oriented equations developed from data collected in the Georgia Piedmont allows estimation of the volume and weight of windrowed logging residues. Easily measured features of the windrows required in the prediction equations are: (1) height, (2) half-width, and (3) average diameter of pieces larger than 3 inches.

INTRODUCTION

Logging residues--entire unmerchantable trees as well as unutilized portions of harvested trees--are often windrowed during site preparation for tree planting in the South. With prices of all fuels rising, organizations that can use wood chips for fuel are beginning to show interest in logging residues (Phillips 1979). The volumes of wood involved can be quite large, particularly on pine-hardwood sites, where many low-quality hardwoods are usually left when a pine stand is harvested (Welch 1980).

Utilization of this material for fuel depends in part upon the ability to estimate the amount and type of material present. I have developed a technique that may be satisfactory on windrowed sites in the Piedmont. This paper has three purposes:

(1) to review the development of the technique,

(2) to present a method for stratified sampling of the windrows on large tracts, and

(3) to demonstrate the system.

DEVELOPMENT OF INVENTORY METHOD

Field Study Sites

Field data were collected from three clearcut pine-hardwood tracts on the Oconee National Forest in the Lower Piedmont of Georgia; all three had been sheared and windrowed after logging. The tracts were on upland sites with gently rolling terrain and predominantly sandy clay soils, eroded from earlier agricultural cropping. The harvested timber stand had a total basal area of about 85 ft^2/ac and consisted primarily of mature loblolly and shortleaf pine sawtimber, with lesser amounts of pine pulpwood. A significant portion of the pine stands consisted of various upland hardwood species including southern red oak, elm, sweetgum, and hickory. Even though many of these hardwoods were larger than 8 inches d.b.h., they were of poor quality with no readily available market. These standing hardwoods had to be removed to regenerate pine.

The sites were prepared by a single local contractor during the late fall and early winter of 1976-77. The residual hardwoods were sheared near ground level with a sharp serrated blade mounted on the front of a crawler tractor. The blade was kept high enough to avoid uprooting stumps and to reduce soil disturbance. After shearing, logging residues and sheared trees were pushed into long piles, or windrows, which followed the land contour. During the spring of 1977, these windrows were studied to determine relationships that could be used to predict the volume and weight of woody material.

Each area was sampled in a systematic manner. Two categories of data, describing either the physical appearance or the biomass contents of the windrow, were collected at about 200-foot intervals along the windrows. At each of the 54 sample points, the following were recorded:

(1) Height of windrow to the predominantly solid surface formed by 3-inch and larger residues.

(2) Half-width--distance from windrow edge to windrow apex.

(3) Mean diameter of residues larger than 3 inches in diameter that were visible on the windrow surface.

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(4) Proportions of the residues that were
    (a) softwoods, (b) soft hardwoods, and
    (c) hard hardwoods.

A complex and time-consuming research procedure was required to determine the actual contents of the windrow at each sample point. A transect through the windrow was formed by rods, which were inserted through the residues to the soil surface at various points where the windrow shape changed. The rods subdivided the windrow into a number of trapezoidal segments, with the groundline and the windrow surface forming two nonparallel ends. The surface profile of the undisturbed windrow was marked on each of the rods and the cross-sectional area determined by summing the trapezoids. A path about 1 foot wide was then cut through the windrow along the transect.

On both sides of this path, each piece of exposed wood was counted and tallied by diameter class if its diameter was less than 3 inches, or measured if its diameter was greater than 3 inches. Depth of displaced soil included in the windrow was noted. Data were collected from a total of 54 sample points and 33 different windrows. Also, similar data were collected from 10 other sample points for testing the prediction equations that would be developed. The field data are summarized in table 1.

Table 1.--Mean physical characteristics of windrows on three Oconee National Forest clearcut tracts used in development of biomass inventory method

Tract	Windrow		Cross-sectional area	Wood ratio
	Height	Width		
	- - *Feet* - -		- - *Feet*^{2} - -	
I	3.4	6.7	24.4	0.17
II	3.9	10.6	29.8	0.15
III	3.3	9.3	23.4	0.19

Data Analysis

The data were analyzed to determine if a prediction equation could be developed to estimate the proportion of the windrow cross-sectional area occupied by solid wood. This dependent variable, referred to as the wood ratio, was calculated as:

$$\text{Wood ratio} = \frac{\text{area of wood (ft}^2)}{\text{area of windrow (ft}^2)} \qquad (1)$$

The independent variables included in the analysis were:

(1) Mean windrow height (feet)
(2) Mean windrow width (feet)
(3) Windrow cross-sectional area (feet^2)
(4) Number of small residue pieces
    (1/4 to 1 inch in diameter)
(5) Number of medium residue pieces
    (1 to 3 inches in diameter)
(6) Number of large residue pieces
    (3 inches and larger in diameter)
(7) Average diameter of large residue pieces
    over 3 inches in diameter
(8) Total count of all intercepted residue
    pieces (number)

Combination of the variables, including various transformations, were used to fit a multivariate equation to the field data.

$$Y_{wr} = b_0 + b_1x_1 + b_2x_2 + \ldots + b_nx_n + E \qquad (2)$$

where: Y_{wr} = wood ratio

b_0, b_1, b_2, b_n are constants

x_1, x_2, x_n are independent variables

E = experimental error

The initial analysis of the data produced a complex 7-variable equation that included several variables related to size and number of large residues measured in the windrow's interior. It was apparent that this equation would not be practical for inventories. Also, I hypothesized that a measure of the number of residue pieces would not be required since dimensions of the windrow could be interpreted as a function of residue number and sizes.

A second analysis was made based only on those variables that could be evaluated easily and quickly by inspection at the windrow sample point. These included: (1) windrow height (feet), (2) windrow width (feet), (3) windrow cross-sectional area (feet), and (4) mean diameter of large residues (inches), plus various combinations and transformations of these variables.

Analysis of this data set resulted in a prediction equation requiring only two variables, with only a slightly greater standard error than the initial 7-variable equation. This equation, which has an R^2 of 0.88 is:

$$\text{Wood ratio} = (0.635 + 0.251/H - 1.625/D)^2 \qquad (3)$$

where: H = windrow height (feet)
D = mean diameter of visible residues larger than 3 inches in diameter

In a separate analysis, I determined that the size of residues visible on the windrow surface is closely related to the size of all residues in the windrow. Therefore, D is easy to determine.

The accuracy of Equation 3 in predicting wood ratio was confirmed using data collected from the 10 additional sample points that were not included in the regression analysis. The results are shown in figure 1, plotted around the line of perfect correlation. Since this equation estimates only the proportion of wood present in the windrow cross section at the sample point, a means of determining windrow area at the sample point was required before residue area could be calculated.

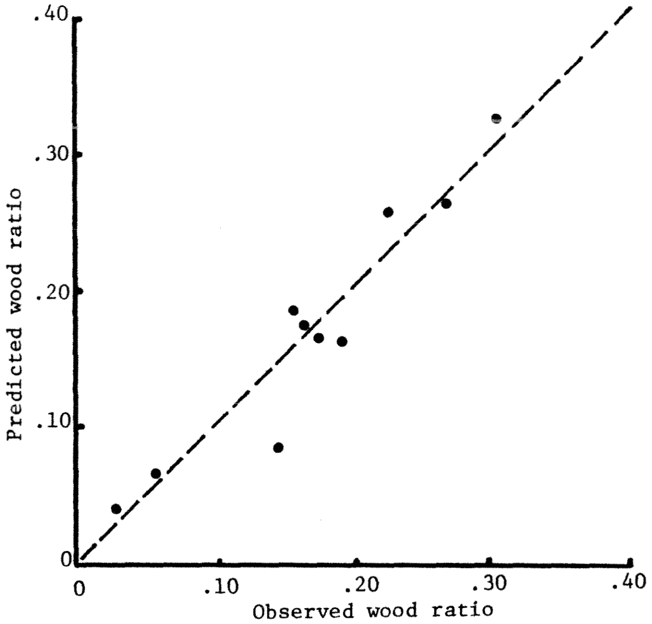

Figure 1.--Relationship of predicted wood ratio to observed wood ratio using data collected from 10 windrow sample points on the Oconee National Forest.

Further analysis of the field data revealed that cross-sectional area of a windrow is fairly easy to estimate with reasonable precision. Acceptable estimates of windrow area were calculated by multiplying height by half-width--the distance from the near edge of the windrow to its highest point (fig. 2). Half-width is easier to measure than full-width because one person can make the measurements without crossing the windrow. As shown in figure 3, estimated area for the 54 sample points was closely related to measured area:

$$\text{MA (ft}^2) = 3.39 + 1.19 \text{ (EA)} \qquad (4)$$

where: MA is measured windrow cross-sectional area and
EA is the estimated area (ft^2).

Equation 4 shows that area was underestimated by about 19 percent, but the R^2 of .96 indicates that the underestimates were fairly consistent. Residue weight per foot-length of windrow was determined using wood density and results from Equations 1 and 3 in the following relationship:

$$\text{Residue wt (lb/ft)} = \text{Windrow area (ft}^2) \times \text{Wood density (lb/ft}^3) \times \text{Wood ratio} \times 1 \text{ Foot} \qquad (5)$$

The result of this relationship is the estimated residue weight contained in 1 linear foot of windrow, for an average sample point. Published values of wood density from the Wood Handbook (U.S. Forest Products Laboratory 1974) may be used, and are presented by species on a basis of 12 percent moisture content. For ease in collecting field data, species may be grouped in classes of softwoods and soft and hard hardwoods. For even more simplicity, an overall mean value of 35 lb/ft^3 wood density may be assumed for windrowed residues on pine-hardwood sites in the Piedmont.

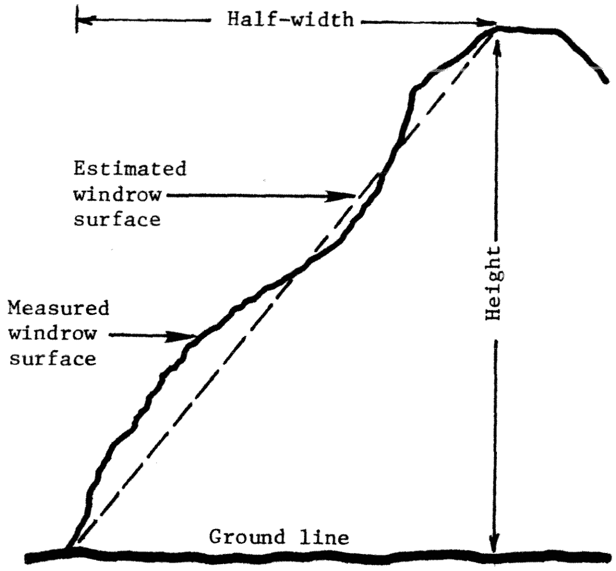

Figure 2.--Windrow cross section showing height and half-width measurements used to calculate cross-sectional area as partial inputs for estimating biomass.

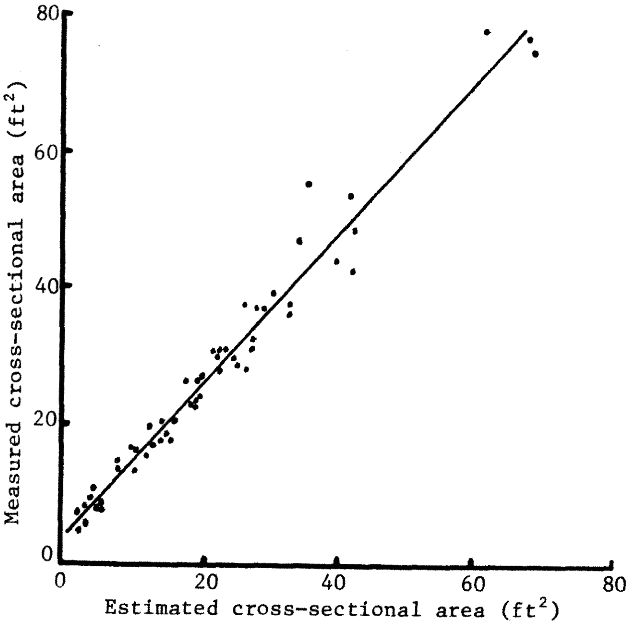

Figure 3.--Relationship of measured windrow cross-sectional area to estimated windrow cross-sectional area determined from 54 sample points on the Oconee National Forest.

Table 2.--Characteristics of windrows and logging residues on middle and upper slope positions of an industrially owned clearcut tract in the Lower Piedmont of Georgia

Subsample location	Points sampled	Windrow			Mean residue diameter	Residues	
		Spacing	Height	Half-width		Windrowed	Scattered
	Number	- - - - -	*Feet*	- - - - - -	- - *Inch* - -	- - - *Tons/ac*	- - -
1	12	163	4.1	5.6	4.6	16.9	5.1
2	9	172	4.8	6.0	4.1	14.1	2.8
3	14	193	5.2	6.1	4.2	14.3	2.5
4	4	93	4.0	5.8	4.0	21.6	3.9
5	10	104	4.1	5.3	4.5	24.0	2.6

Total biomass on the tract is estimated by multiplying the residue weight per linear foot by total length of windrows. On small tracts, it is perhaps easiest to walk along and measure the length of all windrows, while collecting the necessary data from at least 30 sample points. However, this method is time consuming and may be impractical on larger tracts.

SUBSAMPLING WINDROWS ON LARGE TRACTS

In sampling large tracts, it is only necessary to collect data from representative segments of windrows, and to determine the mean spacing between windrows. In the Piedmont, windrow spacing may range from 150 to 250 feet, depending on terrain and amount of residues.

Windrow spacing, in some instances, may not be uniform and individual measurements of windrow spacing are needed. Agricultural terraces, gullies, and wood roads, for example, influence spacing. Particular attention to individual measurement of residue accumulation area should be made when windrows appear larger or smaller than the average size normally seen on the tract.

Combining the windrow spacing with the length of windrow sampled provides an estimate of the area sampled. The area sampled, combined with the total estimated residues on that area, allows calculation of the weight per unit area of windrowed material, which reduces to the relationship:

$$\text{Windrow residue wt (tons/ac)} = \frac{\text{Residue wt (lb/ft)} \times 21.78}{\text{Windrow spacing (ft)}} \qquad (6)$$

In practice, a convenient method of collecting field data, using this subsampling procedure, involves measuring segments of two adjacent windrows, in a "U" pattern, which returns the observer to the starting point. The observer walks along a windrow for perhaps 1,000 feet, stopping to collect sample data at about 200-foot intervals. He then paces to the adjacent windrow, records the distance and collects windrow data in the opposite direction for the same distance. Windrow spacing is again determined as the observer returns to the starting point at the first windrow. Other variations of this basic sampling scheme are obvious.

Similar windrow subsample data should be collected over the entire tract. Subsampling should be systematic and stratified so that ridgetops with light residues and lower slopes with larger amounts of hardwoods are proportionally represented.

EXAMPLE OF APPLICATION OF INVENTORY TECHNIQUE

Logging residues on a clearcut and windrowed industrially-owned tract in the Lower Piedmont of Georgia were inventoried to estimate the biomass remaining after a commercial harvest. Characteristics of the timber stand before harvest are unknown, but about 10 cords of pine and 6 cords of hardwood per acre were harvested.

The tract was similar to the National Forest sites where the biomass estimation technique was developed. Here, however, site preparation consisted of roller chopping, followed by windrowing, instead of KG blading and windrowing. The windrows were similar in appearance to the National Forest site; relatively low, narrow, and with very little soil. A small amount of scattered residues remained between the windrows and helped retard water movement and soil erosion on the cleared site. The large size of the tract, 165 acres, precluded sampling all windrows; 5 subareas were sampled instead. Results of the inventory are summarized in table 2.

About 23 tons of biomass were harvested from this tract. Even with the exceptionally high degree of hardwood utilization practiced by this industrial owner, about 21 tons of the original biomass remain, of which 18 tons are in windrows. Thus, efficiency of total biomass utilization for conventional pulpwood products was about 50 percent. If markets had been available at the time of harvest, whole tree chipping of the larger residual hardwoods for fuelwood could have increased utilization perhaps by another 25 percent. Ideally, evaluation of the potential fuelwood yield should be made during the preharvest cruise, using available prediction equations (Phillips and Saucier 1979).

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IMPACT OF NANTUCKET PINE TIP MOTH ATTACK ON YOUNG LOBLOLLY PINE BIOMASS[1]

R. L. Hedden,[2] J. A. Richmond,[3] H. A. Thomas,[3] and J. H. Lashomb[4]

Abstract.--In a 10-year-old loblolly plantation in Maryland, measurements were made to estimate above-ground biomass of trees which had early protection from Nantucket pine tip moth attack, and biomass equations were developed. A high correlation was found between volume and dry weight. The mean volume (outside bark) for treated trees was estimated as 2.29 ± 0.9 ft^3/tree and for the untreated trees as 0.6 ± 0.25 ft^3/tree, indicating that protection resulted in 280% more volume. The average predicted dry weight of the protected trees was 96.81 lbs while the average predicted dry weight of unprotected trees was 33.35 lbs, *i.e.*, 185% more dry weight in the trees protected from the tip moth. The treated trees had approximately 2X the amount of foliage (dry weight) of the control trees. The results indicate the use of biomass measurement techniques offer important advantages over previously reported methods and that tip moth losses may be larger then previously recognized.

INTRODUCTION

The Nantucket pine tip moth (*Rhyacionia frustrana* Comstock) is a well known pest of loblolly and other species of pine. Numerous studies have been conducted to estimate its impact on young pines, but the circumstances where control measures are warranted are still not well defined. In virtually all cases, the studies showed reduced growth in younger trees, but often, work was not carried beyond about age 10. Measurements tended to show less and less differences with time. It is generally concluded that the advantages of treatment for protection against tip moth (NPTM) tend to wash out or become insignificant by age 18 or 20. For example, in a southwide test, Williston and Barras (1977) showed losses at age 15 due to NPTM which would exceed 300-500 cubic feet/A if projected over a 25-year rotation. They concluded, however, that treatment was not economically justifiable using volume as a criterion.

Tip moth impact is reflected in other tree characteristics as well as height and diameter. Because tip moths destroy new green shoots, we wanted to investigate the effect of tip moth damage on crown morphology and investigate the basic question of destruction of photosynthetic capacity (Lashomb *et al*. 1978) and its outcome. In addition to growth impact, tip moth attack can cause reductions in wood and lumber quality (Hedden and Clason 1980).

The NPTM has two generations per year in the northern parts of its range and as many as six in the Coastal Plain of the southern United States. The number of tip moth generations in a particular region roughly corresponds to the number of growth cycles (flushes) for loblolly and shortleaf pine in that region. As the larvae develop, they feed downward in the newly developing shoots, then into the older shoots formed in the last growth cycle of the tree. The result of this feeding behavior is a net reduction in the potential photosynthetic area of the tree.

Trees may be repeatedly attacked until they are 10-15 feet in height. At this height, loblolly pine growth phenology and shoot morphology

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change. The number of growth cycles declines to one or two per year, and the size of the buds and shoots significantly increase in size. Apparently the trees come under less attack partly because moth emergence is out of phase with shoot growth, and when attack does occur, the trees are better able to tolerate the effects of attack.

We postulated that complete tree above-ground (CTag) biomass measurements would give a more complete picture of tip moth impact than conventional volume estimates and provide better information for the land manager considering control options. The objective of the study therefore was to evaluate the impact of NPTM on loblolly pine in terms of CTag biomass in trees which had received tip moth control.

PROCEDURES

Study Site

The trees were planted in an abandoned alfalfa-clover field at the USDA Agricultural Research Center, Beltsville, MD. The field was divided into 36 plots 12 x 12 feet spaced approximately 10 feet apart. Four species of pines--loblolly pine (*Pinus taeda* L.), Scotch pine (*P. sylvestris* L.), red pine (*P. resinosa* Sit.), and eastern white pine (*P. strobus* L.)--were planted randomly with respect to species on 3-foot centers within each plot. Each species was replicated four times in each plot (= 16 trees per plot). The red, white, and Scotch pine were 4-5 year-old nursery-grown seedlings from Pennsylvania and were planted with bare roots. The loblolly pines were 2-3 year-old pot-grown trees from Virginia and were planted with the rootball intact. The trees were planted in April 1971 in 1-foot diameter by 1-foot deep holes. A soil mix consisting of 50% each of peat moss with 4 ounces of Osmokote^R (18-6-12 NPK)/bushel and soil was packed around the roots.

The plots were divided into two groups: (1) one group of 20 containing untreated trees, and (2) 16 containing trees treated to prevent tip moth attack. During 1971-72 the treated trees were enclosed in 50-mesh Saran screen cages containing three different moth densities (12, 24, 48 adults/cage) to investigate the effect of this variable. Less than 2% of the tips were infested, however, and this part of the experiment was discontinued in 1972. In 1973 the cages were removed before growth began and the trees were sprayed with a 1% solution of dimethoate 2 weeks after the peak moth emergence of each generation. Due to the poor survival of the other species, only the loblolly pines were treated.

In May 1980, after nine complete growing seasons in the field, the dbh and the diameter at the ground line of all trees was measured. Trees for biomass determination and stem analysis were selected proportionally from the diameter distribution of each treatment. Of the 64 original insecticide-treated trees, nine were eliminated due to mechanical damage.

Biomass was determined for 10 trees from each treatment using the procedures slightly modified from Saucier (1979). Dead branches were a very minor component and were not included in the weights. Live branches were pooled for weighing and not stratified by diameter. Biomass equations were developed using standard regression techniques. Both wet and dry weight of each biomass component was modeled as log (weight) = a + b log (D^2H) where D is the diameter at ground line in inches and H is the total height of the tree in feet. Average volume outside bark was determined for each of the 10 insecticide-treated and untreated check trees harvested for biomass determination. Individual tree volume equations for loblolly pine developed by Smalley and Bowers (1968) were used for this purpose.

In addition to the trees sampled for biomass determination, six treated and 21 untreated trees were returned to the laboratory for stem analysis. The stems were split along the pith, and the numbers of leader disturbances (stem breaks) per foot of stem were calculated. The number of leader disturbances has proven to be a relatively good measure of tip moth infestation levels in the past (Hedden and Clason, 1980).

RESULTS AND DISCUSSION

Growth Impact

Between 1972-74 there was significantly less height increment, number of available growing tips, and total tip growth in the trees repeatedly attacked by NPTM. Annual damage was estimated by measuring total growth of uninfested shoots and dieback of each infested tip. Damage (total dieback/total growth x 100) averaged 19.6, 25.8 and 17.7%, respectively, for the 3 years (Lashomb *et al*. 1978). Essentially the destruction of the developing meristems caused shorter internodes and branches resulting in less photosynthetic area (Lashomb *et al*. 1978).

Volume Impact

The average dbh of the 55 insecticide-treated trees in this study was 5.51 in (sd = ±.88), and the average dbh of the 47 attacked trees was 3.54 in (sd = .77). The average volume for the 10 insecticide-treated trees was 2.29 ± 0.90 cubic feet (avg dbh = 5.5 ± .8 in) while the 10 untreated trees averaged 0.60 ± 0.25 cubic feet (avg dbh = 3.5 ± .7 in). Height measurements were not made of the entire stand. However, since the dbh's and standard deviations of the treated and untreated trees corresponded so closely with those of the trees whose heights were measured during biomass sampling, we concluded that these adequately reflect the volume for both larger populations of trees. These data show there was 280% more volume among the trees protected from tip moths. This reduction in volume corresponds to the difference in the number of leader disturbances due to tip moth attack. The untreated trees averaged 0.86 stem breaks per foot while the protected trees had an average of 0.25 per foot.

Biomass Impact

The data for the biomass equations and dry weight are given in table 1. The average green weight of insecticide-treated trees was 201.57 lbs while the average weight of tip moth-attacked trees was 72.95. This difference represents a 64% reduction in biomass where the trees were not protected from tip moths. The average predicted dry weight of the treated trees was 96.81 lbs while the average predicted total dry weight of the unprotected trees was 33.35 lbs. This difference is a 185% increase in total dry weight in the trees with tip moth protection.

Table 1.--Values for biomass regression equation for dry weight (pounds) for tree components by treatment. Equation form: $\ln (W) = a + b \ln (D^2H)$.[1]

Tree component	Intercept (a)	Slope (b)	R^2	$S_{y \cdot x}$
	Insecticide-treated trees			
Total tree	-2.42506	.94241	.86	.15351
Bole	-2.02282	.79920	.80	.15940
Foliage	-5.23155	1.05552	.71	.27231
Branches	-4.84749	1.12258	.83	.20845
	Untreated trees			
Total tree	-1.44521	.78662	.90	.12531
Bole	-2.44481	.82995	.81	.19856
Foliage	-0.88941	.45272	.41	.26839
Branches	-3.80566	.96776	.86	.19574

[1] W = weight in lbs, D = diameter at ground line (in) and H = total tree height (ft).

Similar biomass differences were evident for other component tree parts for the two treatments with the exceptions of the amount of the live crown which was in branches (table 2). We use the term live crown to denote the foliage and branches combined, exclusive of the bole. Among the insecticide-treated trees, 70% of the live crown was branches (dry weight) whereas the trees unprotected from tip moth had 59% of the live crown in branches (table 3).[5] Furthermore, 14% of the total biomass in the protected trees was foliage compared to 21% in the attacked trees although the protected trees had almost 2x more total foliage biomass than the unprotected trees. These differences suggest that the differences in average tree biomass will continue to increase in the future.

Table 2.--Predicted average weights for the components of 10 insecticide-treated and 10 untreated trees.

Tree component	Dry weight	
	Insecticide-treated	Untreated
	lbs	
Total tree	96.81	33.35
Bole	49.69	16.18
Branches	33.05	10.01
Foliage	13.63	7.00

Table 3.--Adjusted dry weights in pounds for the tree component parts by treatment.

Tree no.	D[1]	H[2]	Total tree	Bole	Foliage	Branch
			Insecticide-treated			
1	8.6	25.1	123	55	20	48
2	9.4	26.1	--	--	--	--
3	9.7	26.7	118	57	17	45
4	6.9	26.5	66	40	7	19
5	8.6	25.8	141	73	19	49
6	8.2	27.3	100	52	20	27
7	8.0	21.7	73	38	8	28
8	8.8	22.4	110	61	13	36
9	5.4	22.6	42	24	6	12
10	7.5	24.3	73	37	11	25
			Untreated			
1	7.5	18.6	49	22	10	17
2	4.1	14.0	17	7	5	5
3	6.0	17.7	41	18	8	15
4	6.0	16.4	36	16	11	11
5	5.0	16.7	29	15	7	7
6	4.6	16.3	25	12	6	7
7	4.5	15.8	17	8	5	4
8	6.1	16.1	37	23	4	10
9	5.3	16.3	34	18	7	10
10	7.0	18.0	48	24	9	15

[1] D = diameter at ground line (in).

[2] H = total tree height (ft).

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[5] Data for the adjusted green weights for component tree parts corresponding to the data in table 3 have been omitted but are available from the authors on request.

The differences in biomass observed in this study are extreme and must be interpreted with caution. The study design is atypical in many respects. The initial 3 by 3 foot spacing, screen protection of the insecticide-treated seedlings for one year, and the insecticide treatment itself could have had unknown, but significant effects on the results.

We feel that the observed differences probably represent the largest impact from Nantucket pine tip moth that can be expected to occur. Furthermore, we feel additional, better controlled experiments are necessary to realistically quantify the impact of Nantucket pine tip moth attack on loblolly pine biomass. However, this study represents a starting point for future studies.

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BIOMASS AND NUTRIENT RELATIONSHIPS IN COASTAL PLAIN HARDWOODS[1]

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Abstract.--Increased emphasis on shorter rotations and greater utilization of aboveground biomass through whole-tree harvesting necessitates investigation into nutrient content and distribution in forest stands. Nutrient content information is presented for water tupelo, water oak, and black gum growing in varying site conditions. Results show that elemental concentrations decrease in the order foliage > branches > stem bark > stem wood although this trend varies somewhat with nutrient and species. Actual nutrient content occurs in the order stem wood > branches > stem bark > foliage. Whole-tree harvesting can increase biomass removal over stem harvesting by about 25% and nutrient removal by about 25-120% depending upon species, element, and season of harvest.

INTRODUCTION

Improved harvesting efficiency and product utilization have been the impetus behind increasing whole-tree harvesting or removal of all aboveground biomass. The recent growth of interest in new energy sources and the extension of harvesting into stands previously considered to be unmerchantable have been offered as reasons for the growing trend toward increasing the degree of forest utilization (Morrison and Foster 1979). Concerns have arisen that this harvesting system may lead to decreased forest productivity through soil nutrient depletion (Borman et al. 1968, Boyle et al. 1973, White 1974). Nutrients contained in standing biomass represent just one segment of the total site nutrient pool. To fully evaluate the impact of intensive harvesting on site productivity, the complete forest nutrient cycle must be considered.

Forest nutrient cycling consists of inputs, cycling within the system and outputs. In undisturbed forests, inputs are normally small but sufficient to balance outputs since nutrient losses from undisturbed forests are minimal (Haines 1978). The annual nutrient uptake by most forest species is on the same order as that of many agricultural crops, but because a major portion of the absorbed nutrients are returned to the forest floor, or translocated within the tree, relatively small amounts are retained each year in an annual accretion of biomass (Pritchett 1979). Rolfe et al. (1978) have found that in a mature Illinois oak-hickory forest 80 percent of the total site nutrient pool was in the soil, 15 percent in the above ground biomass, 4 percent in root systems and 1 percent in the forest floor litter.

The largest nutrient removal from the forest system occurs in the harvesting procedure and can result in substantial losses. The effects of timber harvesting on the nutrient cycle depends upon intensity and frequency of removals, site disturbance, and pre-harvest site conditions. Nutrients removed in wood and bark comprise only a small fraction of the site's total nutrient reserves (Rolfe et al. 1978). Foliage and branches contain the largest nutrient concentrations and it is the harvesting of this material that can dramatically increase nutrient removal from the site. Conventional tree harvesting which removes only the main portions of the stem leaves large quantities of nutrient-rich biomass on the site. In contrast, short rotation intensive culture (SRIC) systems may double normal biomass removals

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and consist of a series of shorter rotations which considerably promotes nutrient depletion from the site (Boyle 1975).

An apparent need has developed for reliable estimates of stand nutrient content and distribution for commercial species. White (1974) states the importance of foresters establishing the rate and amounts of nutrients removed from sites by SRIC systems as well as whole-tree harvesting of older stands. Such data is being generated through an ongoing project by the North Carolina State University, Hardwood Research Cooperative, and the U. S. Forest Service, Southeastern Forest Experiment Station at Athens, Georgia.

A comprehensive and detailed study was designed for mixed southern hardwoods in the Coastal Plain, Piedmont and Southern Appalachian Mountains. The Southern Hardwood Forest Resource represents about forty percent of the total commercial forest land and contains about fifty-one percent of all forest growing stock making it potentially the region's most important resource. The study integrates area plot sampling and sampling individual trees adjacent to area plots. Accurate stand data are documented as well as supplementary information necessary to complete needed diameter classes of the major species found on the area plots.

The initial phase of the study is being conducted in the Gulf and Atlantic Coastal Plains. Even-aged stands of mixed hardwoods are being sampled to quantify biomass, energy yields, nutrient content and distribution, and other subordinate vegetation and soils information. It is anticipated that this information will form a comprehensive biomass, nutrient and energy content data base for the Southern Hardwood Forest.

Table 1. Distribution of 19[1] one-tenth-acre (.04 ha) Coastal Plain biomass plots established by the N. C. State Hardwood Research Cooperative during 1978-79.

Age Class	Site Type, Location, Cooperator and Plot Number Bottomland	Wet Flat	Swamp
10	(16) Sumter Co., AL American Can Co. (18) Bertie Co., NC Georgia-Pacific Corp.	(20) Duvall Co., FL Container Corp.	
20	(10) Warren Co., MS International Paper Co. (13) Sumter Co., AL American Can Co.	(19) Taylor Co., FL Buckeye Cellulose Corp.	(15) Nassau Co., FL Rayonier, Inc.
40	(2) Dallas Co., AL Hammermill Paper Co. (3) Southampton Co., VA Union Camp Corp. (1) Marion Co., SC International Paper Co.	(9) Washington Co., AL Scott Paper Co. (7) Taylor Co., FL Buckeye Cellulose Corp.	(5) Craven Co., NC Weyerhaeuser Co. (4) Hertford Co., NC Union Camp Corp.
60	(11) Wayne Co., MS Scott Paper Co. (14) Escambia Co., FL St. Regis Paper Co.	(6) Craven Co., NC Weyerhaeuser Co.	(12) George Co., MS Masonite Corp. (8) Taylor Co., FL Buckeye Cellulose Corp.

1/ Plot 17 was established on the Piedmont.

METHODS

Twenty-four circular one-tenth acre (.04 ha) plots are being distributed in mixed, even-aged hardwood stands in the Atlantic and Gulf Coastal Plains. Two replications each of four age classes (10, 20, 40 and 60 years) are being located in three site types: (1) bottomland--floodplain areas adjacent to stream drainages, predominantly of loam or silt loam soils, (2) wet flats--broad, interstream areas with poorly-drained nonalluvial soils, and (3) swamps--including peat and muck swamp interstream areas characterized by heavy organic matter accumulation and very poor drainage. Plots are randomly located within stands to complete this site type-age class matrix. These sites support stands which make up the largest proportion of commercial hardwoods in the Coastal Plain. Presently, 19 plots have been installed (Table 1).

Soil, litter, understory vegetation, sapling trees and pulpwood and sawtimber trees are being sampled. This paper is limited to the sawtimber and pulpwood trees. Pulpwood trees 5.0-10.9 inches (12.7-27.7 cm) and sawtimber trees > 11.0 inches (27.9 cm) in diameter on plots are felled and measured for total height and heights to various merchantable diameter outside bark (dob) limits. Disks approximately 1.5 inches (3.8 cm) thick are removed at stump height, breast height, at quarter points up the stem to a 4.0 inch (10.2 cm) dob and at 2.0 inch (5.1 cm) dob for nutrient content analysis. A maximum of three trees per species, per diameter class is used for the above determinations. Stems are cut into short sections and weighed green in the field to the nearest 0.1 pound (0.05 kg) on a 300 pound (136.1 kg) capacity portable scale. From each tree, three sample branches are cut at 2 inches dob from lower, middle and upper crown and weighed with foliage and small branches ($\leq$ 0.5 inches) intact. The foliage is removed and sample branches reweighed. Small branches ($\leq$ 0.5 inches) are removed and sample branches reweighed excluding foliage or small branches. All other branches are cut from the bole and segregated into three size classes: extra large (> 4.0 inches dob), large (2.0-4.0 inches dob), and medium (< 2.0 inches dob). One disk is taken from each category for nutrient content analysis. Individual trees of major species are sampled and processed in the same manner as those within the area plots as necessary to acquire a minimum of 3 trees/1 inch size class on a given site type.

Green weight of each disk with bark is measured to the nearest 0.1 gram and minimum and maximum dob recorded. Disks are debarked and weighed to the nearest 0.1 gram with minimum and maximum dib recorded. The disk and a representative bark subsample are dried at 60°C. Branch samples are processed in the same manner except for branches less than 0.5 inches and .5-2 inches where wood and bark are not separated. Samples are ground in a Wiley Mill fitted with a 20 mesh stainless steel screen. Total nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), and Magnesium (Mg) are measured following wet ashing; N and P are determined colorimetrically as the ammonia salicylate and phosphomolybdenum complexes respectively; K, Ca, and Mg are determined by atomic absorption spectrophotometry.

RESULTS

Nutrient data are presented for three major species: water typelo (*Nyssa aquatica* L.) from plot 4, water oak (*Quercus nigra* L.) from plots 7 and 11, and black gum (*Nyssa sylvatica* Marsh.) from plot 12 (Table 1). All plots were sampled in late summer or early autumn when nutrient concentrations have been shown to be most stable (Bowersox and Ward 1977).

Several trends occurred consistently in the nutrient concentrations in all three species (Tables 2, 3, and 4):

- Nutrient concentrations were generally higher in bark than in wood for all elements, particularly for Ca.
- The order in which nutrient concentrations occurred by component was foliage > branches > stem bark > stem wood except for Ca where the order was stem bark > branches > foliage > stem wood.
- Nutrient concentrations in bark varied less among bole positions than those in wood, except for Ca where the opposite trend occurred.
- Nutrient concentrations in stem wood generally decreased from the butt to mid-bole, then increased with bole height thereafter.
- Magnesium and P varied least of all elements with bole height in wood and bark.
- There was generally a decrease in nutrient concentration with increasing branch diameter in both branch wood and bark except in the case of Ca in branch bark where the opposite trend occurred.
- The order in which nutrients occurred in bole bark was always Ca > N > K > Mg > P.

The above trends also occurred in other bottomland hardwood species growing in similar stands (Messina 1980).

Table 2. Average percent concentration of five elements by sampling position for six water tupelo trees (DBH range 5.9-19.9 inches).

			Percent Concentration		
Sampling Position	N	P	K	Ca	Mg
Leaves	1.24	.10	.60	.83	.33
Branches <.5" (wood and bark)	.37	.05	.22	.67	.11
Branches .5"-2" (wood and bark)	.22	.03	.14	.26	.05
Branches 2"-4"					
Wood	.13	.02	.10	.09	.03
Bark	.39	.03	.12	.89	.10
Branches > 4"					
Wood	.13	.02	.08	.11	.03
Bark	.32	.02	.08	1.05	.07
Stem Wood					
Butt	.12	.02	.12	.16	.05
DBH	.10	.02	.10	.20	.04
1/4 height	.10	.02	.10	.14	.04
1/2 height	.11	.02	.09	.13	.03
3/4 height	.13	.02	.10	.12	.04
4" dob	.13	.03	.10	.10	.04
2" dob	.15	.03	.13	.10	.04
Stem Bark					
Butt	.42	.03	.12	3.34	.15
DBH	.35	.03	.11	2.19	.11
1/4 height	.35	.02	.11	1.62	.11
1/2 height	.35	.02	.11	1.35	.09
3/4 height	.37	.02	.11	1.21	.10
4" dob	.38	.03	.14	1.10	.12
2" dob	.43	.03	.19	1.38	.16

Table 3. Average percent concentration of five elements by sampling position for six water oak trees (DBH range 5.5-13.9 inches).

			Percent Concentration		
Sampling Position	N	P	K	Ca	Mg
Leaves	1.38	.12	.43	1.11	.17
Branches < .5" (wood and bark)	.53	.10	.29	1.55	.11
Branches .5"-2" (wood and bark)	.41	.07	.18	.87	.06
Branches 2"-4"					
Wood	.19	.03	.24	.15	.03
Bark	.30	.02	.08	2.56	.03
Branches > 4"					
Wood	.12	.02	.26	.14	.02
Bark	.29	.02	.08	2.66	.03
Stem Wood					
Butt	.12	.01	.12	.23	.03
DBH	.11	.01	.10	.15	.02
1/4 height	.09	.01	.10	.14	.02
1/2 height	.11	.01	.15	.16	.02
3/4 height	.12	.01	.20	.16	.03
4" dob	.16	.02	.17	.16	.03
2" dob	.25	.03	.15	.15	.04
Stem Bark					
Butt	.31	.02	.08	3.43	.03
DBH	.29	.02	.09	2.80	.03
1/4 height	.28	.01	.11	3.32	.03
1/2 height	.28	.02	.09	2.99	.03
3/4 height	.27	.02	.08	2.43	.03
4" dob	.31	.02	.06	2.14	.03
2" dob	.37	.02	.07	2.06	.04

Table 4. Average percent concentration of five elements by sampling position for six black gum trees (DBH range 5.3-16.1 inches).

			Percent Concentration		
Sampling Position	N	P	K	Ca	Mg
Branches < .5" (wood and bark)	.46	.06	.22	.66	.10
Branches .5"-2" (wood and bark)	.27	.03	.13	.33	.05
Branches 2"-4"					
Wood	.11	.02	.10	.10	.03
Bark	.42	.03	.15	1.33	.12
Stem Wood					
Butt	.16	.02	.10	.14	.03
DBH	.13	.02	.08	.14	.03
1/4 height	.14	.02	.07	.11	.03
1/2 height	.15	.02	.08	.11	.03
3/4 height	.17	.03	.09	.13	.03
4" dob	.18	.03	.09	.13	.03
2" dob	.23	.04	.10	.12	.03
Stem Bark					
Butt	.54	.04	.21	3.00	.13
DBH	.52	.04	.18	2.80	.10
1/4 height	.43	.03	.15	2.36	.10
1/2 height	.38	.02	.13	1.93	.09
3/4 height	.39	.02	.15	1.80	.08
4" dob	.43	.03	.17	1.65	.11
2" dob	.47	.04	.18	1.52	.11

Water Tupelo

Nutrient concentrations followed the aforementioned general trends (Table 2). In stem wood, most elements showed significant differences in concentration (P = .05 level) between butt disk and 2-inch dob disk except K and Mg; for stem bark only K and Ca concentration differences were significant. The order in which nutrients occurred in stem wood is Ca > N > K > Mg > P; for foliage the trend is N > Ca > K > Mg > P.

Water Oak

Elemental concentration trends (Table 3) were similar to those in water tupelo. An exception was the order in which nutrients occurred in stem wood: Ca > K > N > Mg > P. In stem wood, only N and P showed significant differences in concentration between butt and 2-inch dob disk; in stem bark, it was N and Ca concentrations that differed significantly.

Black Gum

Nutrient concentration trends (Table 4) resembled those cited for all other species. The hierarchy of nutrient concentration for stem wood was N > Ca > K > Mg > P. In stem wood, only N and P showed significant differences in concentration between butt and 2-inch dob disk; in stem bark, only Ca showed significant differences between both positions. Foliage data is lacking for black gum because the plot on which it occurred was sampled following leaf abscission.

Tables 2, 3, and 4 show that whole-tree harvesting will remove tree components containing the highest nutrient concentrations rather than leaving them as slash. To evaluate the additional nutrient removals from whole-tree harvesting, nutrient concentrations must be coupled with biomass data to determine actual nutrient weights contained in each tree component.

Table 5 illustrates relationships between biomass and nutrient content in water tupelo.

Table 5. Dry weight and nutrient content of water tupelo expressed as a percentage of whole-tree totals.

Component	Wt.	N	P	K	Ca	Mg
Bole Wood	75.6	51.3	58.6	67.2	37.4	57.8
Bole Bark	8.3	17.1	10.3	7.8	44.3	15.3
Bole Subtotal*	83.9	68.4	68.9	75.0	81.7	73.1
Top Wood	2.6	2.7	5.3	3.3	0.8	2.3
Top Bark	0.5	4.0	2.7	2.3	4.0	3.6
Branches	11.5	15.3	16.5	12.4	10.1	12.4
Foliage	1.5	9.6	6.6	7.0	3.4	8.6
Top Subtotal	16.1	31.6	31.1	25.0	18.3	26.9

* Stump to 4-inches diameter-outside-bark.

These data can be useful when assessing the extent of nutrient removal associated with harvesting systems. A harvest of total aboveground material will increase biomass removal by approximately 19% over a conventional bole harvest to a four-inch top. However, such a harvest would increase nutrient removals by the following percentages; N, 46; P, 45; K, 33; Ca, 22; and Mg, 37. It is interesting to note that although the bole wood weight is nearly nine times that of bole bark, the bark contains substantially more Ca than the bole wood owing to the comparatively high Ca concentrations in bark tissue. The elements least affected by increasing biomass removal are potassium and calcium due to the large amounts of potassium in bole wood and calcium in bole bark.

The additional nutrient depletion effect of whole-tree harvesting of water oak is relatively greater than that for water tupelo (Table 6).

Table 6. Dry weight and nutrient content of water oak expressed as percentage of aboveground totals

Component	Wt.	N	P	K	Ca	Mg
Bole Wood	68.2	31.8	28.6	62.7	13.1	40.8
Bole Bark	10.9	13.7	7.5	7.1	46.1	10.1
Bole Subtotal*	79.1	45.5	36.1	69.8	59.2	50.9
Top Wood	1.9	2.3	3.4	1.7	0.4	3.2
Top Bark	0.7	1.1	0.6	0.2	1.9	0.7
Branches	14.8	26.2	37.8	17.5	33.2	26.4
Foliage	3.5	24.9	22.1	10.8	5.3	18.8
Top Subtotal	20.9	54.5	63.9	30.2	40.8	49.1

* Stump to 4-inches diameter-outside-bark.

Whole-tree harvesting would increase biomass removals by 26% while N removals would be increased by 120%, P by 177%, K by 43%, Ca by 69%, and Mg by 97%. Calcium and K show the least increases as also observed with water tupelo.

The black gum data (Table 7) shows a reduction in whole-tree harvesting nutrient removal effect as compared to water tupelo and water oak since it was sampled after leaf abscission.

Table 7. Dry weight and nutrient content of black gum expressed as percentage of aboveground totals.

Component	Wt.	N	P	K	Ca	Mg
Bole Wood	80.1	66.1	92.2	75.5	35.1	58.6
Bole Bark	7.8	15.5	2.3	9.6	50.7	17.5
Bole Sub-total*	87.9	81.6	94.5	85.1	85.8	76.1
Top Wood	2.6	3.8	1.4	2.6	0.8	2.2
Top Bark	0.7	2.0	0.4	1.2	3.5	2.2
Branches	8.8	12.6	3.7	11.1	9.9	19.5
Top Sub-total	12.1	18.4	5.5	14.9	14.2	23.9

* Stump to 4-inches diameter-outside-bark.

Whole-tree harvesting would increase biomass removals by 14% while N removals would be increased by 23%, P by 6%, K by 18%, Ca by 17%, and Mg by 31%. Since black gum was sampled after leaf abscission, only a general comparison can be made between this species and water tupelo and water oak.

Several factors must be considered when applying data such as that presented for water tupelo, water oak and black gum. It has been shown that just prior to leaf abscission all macronutrients and most micronutrients undergo some degree of translocation back from leaves into twigs (Likens and Bormann 1970). Therefore, post-abscission nutrient removals must be evaluated through sampling after leaf fall since subtracting foliage content from pre-abscission data will provide erroneous results.

Tables 5, 6, and 7 estimate nutrient removal from the site in biomass and do not show true system losses, particularly for nitrogen. Nitrogen losses can occur through leaching and denitrification as well as harvest removal. Rauscher (1980) determined that the greater the litter amount on the site after a harvest, the greater the loss of nitrogen from the system by leaching and denitrification. A whole-tree harvest will produce less litter than a bole harvest; therefore, the greater removal of N in biomass will be partially offset by the lower leaching and denitrification losses.

It is stressed that the estimates of removal provided are valid only for the species discussed growing in similar stand situations. Nutrient content is rather variable between species and even between trees of a single species growing in the same stand.

SUMMARY AND CONCLUSIONS

Several conclusions were drawn concerning nutrient levels and distribution in water tupelo, water oak, and black gum.

- Whole-tree harvesting can increase biomass removal over stem harvesting (stump to 4-inches diameter-outside-bark) by 20-26% and nutrient removal by 22-117% for a pre-abscission harvest.
- Elements most affected by whole-tree harvesting will be N and P; those least affected will be K and Ca.
- Elemental content by tree component was generally bole wood > branches > bole bark > foliage except for Ca where the order was stem bark > branches ≃ stem wood > foliage.

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BIOMASS AND NUTRIENT ACCUMULATIONS OF AN UNEVEN-AGED SOUTHERN PINE STAND IN ARKANSAS[1]

Timothy T. Ku, Laurin Wheeler, Jack F. Young,
Robert J. Colvin, Michael F. Dziadzio
and John H. King[2]

Abstract.--Destructive sampling was used to determine the aboveground biomass and nutrient content of overstory components in a natural, uneven-aged loblolly (Pinus teada L.) and shortleaf (Pinus echinata Mill.) pine stand on a Sacul soil of the Upper Coastal Plain region in south Arkansas.

The soil was Sacul loam, a clayey, mixed, thermic, Aquic Hapludult, on a moderately well-drained upland pine site. The stand from which the sample trees were harvested had 532 stems/ha (10 cm dbh and over), 22.7 M^2/ha of basal area. The largest trees were 77 years old. The ratio of loblolly to shortleaf pine in the stand was nearly 2:1 in both number of trees and in basal area per hectare. Diameter distribution of the stand had a q-value of approximately 1.56.

The felled sample trees were separated into component parts in the field. Standard procedures were used to determine the biomass dry weight at 70°C. Subsamples from each tree component were ground for chemical analysis of N, P, K, Ca, and Mg.

The least squares method was used to determine the relationship between tree components and D^2H, where D was dbh and H was total height of the sample tree. Regression equations of the general form:

$$\ln(\text{Biomass of Tree Components}) = A + B\ \ln(D^2H)$$

were used with stand tables to estimate biomass of each tree component. The stand dry weights in stemwood, stembark, live branches, dead branches and needles were: 80, 8, 16, 2 and 5 dry metric tons per hectare (T/ha), or 72, 7, 15, 2 and 4 percent of the total biomass, respectively. Total biomass production was 111 T/ha.

Nutrient accumulation of N, P, K, Ca and Mg in the total biomass were: 191, 9, 36, 69, and 33 Kg/ha, respectively. 40% of N and P, and 60% of K, Ca, and Mg were accumulated in the stems.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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INTERACTION OF SITE, CULTURAL PRACTICES, AND TREE SPECIES ON DRY MATTER ACCUMULATION IN BIOMASS PLANTATIONS

P. E. Pope and J. D. Rhodes[1]

Abstract.--After two growing seasons black locust averaged 317 and 189 cm in height and 25 and 26 mm in diameter on the forest land (FL) and old field (OF) sites, respectively. Sycamore averaged 109 and 95 cm in height and 14 and 11 mm in diameter on the FL and OF sites, respectively after the same period of time. Initial spacing and fertilization had no effect on seedling survival but increased spacing significantly increased average seedling dry weight. Total aboveground biomass was significantly influenced by tree species, site, fertilization and initial spacing. The OF site showed the greatest growth response for fertilization.

INTRODUCTION

An uninterrupted supply of wood fiber is essential to accommodate a growing forest products industry. Wood is also the largest biomass energy resource in the United States and its importance as an alternate of supplemental fuel is dramatized by recent fossil fuel shortages. The Office of Technology Assessment (1980) indicates woody biomass, in addition to its traditional uses, will play a major role in future energy production through gasification or conversion to liquid fuels. In the short run most of the energy resource needs from biomass is expected to come from residues in conventional harvesting but an increase in the intensity of forest management, including the establishment of biomass/silage plantations, is essential to achieve the projected energy yield from wood while maintaining the supply of material to forest industries.

Closely spaced, short rotation and intensively cultured fiber plantations can contribute large quantities of biomass (McAlpine et al., 1966; Kormanik et al., 1973; Kennedy, 1975 and Wittwer et al., 1978). Factors which influence fiber yields include site (Broadfoot et al., 1971; Wittwer et al., 1978), site preparation (Carter and White, 1970), planting stock (Kennedy, 1972; Steinbeck and McAlpine, 1973; Belanger and Saucier, 1975), spacing (Belanger and Pepper, 1978; Wittwer et al., 1978), cultural treatments, including weed control (McKnight, 1970) and fertilization (Blackmon and White, 1972), and harvesting interval (Balanger and Saucier, 1975; Kennedy, 1975; Perala, 1979) and season (Clark, 1975; Balanger, 1979). In addition, efforts have been made to determine the productive potential of root stocks (Balanger, 1979; Perala, 1979) and to access the impacts of short rotations and intensive harvesting on long term site productivity (Blackmon, 1979; DeBill and Radwan, 1979).

In many areas of the country, sites relegated for forestry use are stressful and are marginally productive. The objectives of this study are to compare the productivity of a stressful site to a typical forest land site and to determine the influence of tree species, fertilization and spacing density on dry matter yields.

MATERIALS AND METHODS

Species and Site Selection

Two tree species, black locust (Robinia pseudoacacia L.) and American sycamore (Platanus occidentalis L.) were selected for evaluation of dry matter production under the short rotation/silage plantation concept. Two planting sites were identified: (1) abandoned old field and (2) forest land (Table 1). A fragipan is present in both the old field and forest land soils at 38 and 110 cm, respectively.

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Table 1.--Site characteristics of the two locations assessed for woody biomass production.

	Old Field	Forest Land
Soil Type	Zanesville (Typic Fragidalfs, fine-silty, mixed mesic) Eroded Phase	Fincastle (Aeric, Ochraqualfs [Typic], fine-silty, mixed, mesic) Somewhat Poorly Drained
Slope (%)	5-7	1-3
Aspect	SW	-
Estimated Site Index[1]	55-60	85-90

[1] Site index at a base age of 50 years for Yellow poplar (Liriodendron tulipifera).

Spacing

Prior to experimental plot layout, the old field and forest land sites were plowed and disced in the fall of 1978 in preparation for seedling planting in May 1979. One-year-old bareroot nursery seedlings were planted in pure stands at densities equivalent to 5,000, 10,000 and 20,000 plants per ha, representing spacings of 2 x 1, 1 x 1 and 0.5 x 1 meters.

Fertilization and Weed Control

Following site preparation soil samples 0-30 and 30-60 cm in depth were collected from 25 locations identified at random on each site and analyzed for chemical properties. Similarly, soil samples were collected in September each year from one random location in each of the 36 subplots on each site and analyzed (Table 2). Available soil P was determined colorimetrically using ammonium molybdate reagent following extraction with Bray I solution, available K, Ca and Mg determinations followed extraction with IN ammonium acetate, and NH_4-N and NO_3-N values were determined following 2N KCl extraction and Kjeldahl distillation.

Fertilizer treatments, applied in May 1979 and 1980, consisted of no fertilization or a broadcast application of N, P and K at rates equivalent to 100, 50 and 50 kg/ha, respectively, of elemental material for sycamore and P and K each at 50 kg/ha of elemental material for black locust. In all cases nitrogen was added as ammonium nitrate, phosphorus as superphosphate and potassium as potash. Weed control was provided by mechanical cultivation during early June and by mowing in mid-July and late August or as needed.

Experimental Design

At each location, the two species and two fertilizer treatment combinations were randomized over three blocks forming 12 main plots. The three spacings were randomly assigned to subplots within each main plot. Each subplot was 12 x 12 meters. All trees in the center 32 m^2 of each subplot (net plots) were measured. This arrangement provides for a minimum of 27 measurement trees for the 2 x 1 m spacing, 45 trees for the 1 x 1 m spacing and 81 trees for the 0.5 x 1 m spacing. Inherent with spacing studies is the necessity of choosing between unequal subclass numbers when a unit area constitutes the measurement plot or risking heterogeneity of variance if surface area varies. The study was arranged in a randomized complete block design and analyses based on unequal sample size.

Data Acquisition and Analysis

Stem height, diameter at a 10 cm height, and survival were determined annually for all plot trees. Six sample stems were harvested annually from the interior border rows and height, diameter at 10 cm stump height, and green and oven dry weight of foliage and stem components determined. Biomass of the net plot trees was estimated by a biomass to volume model determined for the harvested trees. All data were analyzed by ANOVA and Duncan's new multiple range test.

RESULTS AND DISCUSSION

Black locust seedling survival, and first and second year height and diameter growth exceeded the survival and growth attained by sycamore for the two sites investigated. After two years seedling survival averaged 96% for locust and 84% for sycamore and was not affected by site or cultural treatments. After the first and second growing seasons black locust growing on the forest land (FL) site was significantly taller and larger in diameter than locust seedlings grown on the old field (OF) site (Table 3). However, after the second growing season, the growth advantage associated with fertilizing black locust was no longer evident for either the FL or OF site. After the first growing season, the height and diameter growth of sycamore was not influenced by site and fertilization; however, by the end of the second growing season, fertilization significantly increased the height and diameter of sycamore on the OF site. Differences in inherent site productivity are also beginning to emerge. Seedlings receiving no fertilizer and grown on the PFL site were significantly larger than seedlings for the identical treatment on the OF site.

Site and initial spacing significantly influence the individual aboveground dry weight of black locust seedlings (Table 4). After two

Table 2.--Chemical analysis of the three biomass sites before fertilization and after one growing season. (Unless otherwise indicated, all values are reported as ppm.)

	Forest Land				Old Field			
	May 1979[1] (cm)		September 1979[2] (cm)		May 1979 (cm)		September 1979 (cm)	
	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60
pH	6.4	5.8	6.2	5.9	5.6	5.3	5.4	5.3
O.m(%)	1.2	0.4	1.3	0.6	1.5	0.4	1.3	0.6
NH_4-N	1.8	1.4	1.6	1.8	2.6	1.5	2.0	1.7
NO_3-N	2.0	3.0	1.9	2.6	0.8	1.6	1.2	1.6
P	20	3	32	51	2.5	2.5	12.5	3
K	125	100	133	109	40	46	78	52
Ca	1460	1933	1371	1900	500	546	471	540
Mg	340	590	361	560	100	257	93	265

[1] Chemical analysis before fertilization.

[2] Chemical analysis after one growing season.

Table 3.--Fertilization, species and land classification influence seedling height and diameter growth after 1 and 2 years.

	Black Locust				Sycamore			
	Fertilized		Not Fert.		Fertilized		Not Fert.	
Land Classification	Ht. (cm)	Diam. (mm)	Ht. (cm)	Diam. (mm)	Ht. (cm)	Diam. (mm)	Ht. (cm)	Diam. (mm)
Forest Land								
Year 1	162 x [1],*[2]	16.4x	117x	16.1x	83x	9.7x	69x	8.2x
Year 2	331a[1]	27.7a	304a	.1a	113a	13.8a	104a	13.8a
Old Field								
Year 1	73y*	7.1y	42y	6.3y	61x	9.2x	43x	8.5x
Year 2	169b	12.4b	169b	12.9b	109a*	12.2a*	80.2b	9.6b

[1] Column values for a given species and year not followed by the same letter are significantly different (α = .05). Note: x-y for year 1; a-b for year 2.

[2] Row values for a given growth variable, species, land classification and year having a * are significantly different (α = .05).

growing seasons, black locust seedlings averaged 1297 g/seedling on the FL site and 248 g/seedling on the OF site. For the FL site, the average total aboveground dry weight increased from 992 g to 1734 g/seedlings as initial spacing increased from 0.5 x 1 to 2 x 1 m spacings. This trend was reversed for locust growing on the OF site. Seedlings grown at the 0.5 x 1 m spacing had significantly more dry weight than seedlings grown at the 2 x 1 m spacing.

On the average, after two years, American sycamore accumulated 50 g of dry matter per seedling. On the FL site, seedling dry weight increased as initial spacing increased with significant gains noted for the 2 x 1 m spacing. Dry matter accumulation on the OF site was also influenced significantly by spacing but no clear reason for the observed response can be offered.

As planting spacings become wider, seedlings tend to become more branchy, have relatively more foliage and develop larger diameters. These generalizations appear to explain the growth response observed for black locust and sycamore on the FL site. The larger locust seedlings associated with the closer spacings on the OF site may have resulted from a reduction of interrow weed competition. Weed control was achieved by lightly tilling down each row in early June of each year followed by a down the row mowing in early July and August. Consequently, as seedling spacing increased the amount of competing vegetation also increased. While this same analogy also applies to the FL site, the species components of the competing vegetation differed greatly. The old field site was characterized by woody shrubs, scrub hardwood species, fescue and broomsedge while the PFL site supported annual

Table 4.--Influence of land classification and spacing on the dry matter of black locust and sycamore seedlings after 2 growing seasons. Values are present as grams/seedling).

Land Classification	Black Locust Spacing (m)	Black Locust Dry Wt. (grams)	Sycamore Spacing (m)	Sycamore Dry Wt. (grams)
	.5 x 1	992b[1]	.5 x 1	45a
Forest Land	1 x 1	1167ab	1 x 1	44a
	2 x 1	1734a	2 x 1	62b
	.5 x 1	262c	.5 x 1	40a
Old Field	1 x 1	275c	1 x 1	61b
	2 x 1	207d	2 x 1	46a

[1] Column values not followed by the same letter are significantly different ($\alpha = .05$).

grasses, foxtail, pigweed and pokeberry.

Obviously, the two tree species differ in their ability to respond to the sites and cultural practices tested. Black locust is a nitrogen-fixing species, and therefore capable of continuously supplying this essential element, which is capable of vigorous growth over a range of site conditions. American sycamore is more site specific than locust and is apparently not as competitive for soil moisture and nutrients. Sycamore is capable of rapid growth rates under the correct site conditions but it appears that these conditions have not been met in this study.

The total aboveground dry matter attained after two growing seasons is influenced by tree species, spacing, site and fertilization (Table 5). In general, biomass production was greatest for black locust on the FL (13.3×10^3 kg/ha) followed by the OF site (2.8×10^3 kg/ha). Dry matter production for sycamore averaged 0.54×10^3 kg/ha and was not significantly influenced by site.

For both species dry matter production/ha increased as initial spacing decreased from 2 x 1 to 0.5 x 1 m. Yield (10^3 kg/ha) is a function of individual plant size and plantation density. The yield values reported are illustrative of the importance of stand density in determining dry matter production of short rotation cellulosic crops.

Fertilization of black locust seedlings growing on the FL or OF sites at the 0.5 x 1 m spacing significantly reduced the dry matter production when compared to the unfertilized control (Table 5). Fertilization caused rapid early stem growth and foliage development, particularly for those trees in the closest spacing. Weed competition was minimal because the densely planted trees had, in effect, eliminated them and any added fertilizer was readily available to the locust seedlings. A severe drought in June and July 1980 stressed all trees but caused the densely planted fertilized seedlings to stop growing. Fertilized trees planted at wider spacings were not as severely affected. Competing vegetation may have absorbed much of the added fertilizer making it unavailable to the locust seedlings. While this obviously reduced the rate of early season growth, the seedlings appeared to be not as susceptable to drought stress as the rapidly growing seedlings. Fertilization had little effect on dry matter production on the FL site but may be essential to attain acceptable fiber yields on old field sites.

Sycamore yields, after two growing seasons, followed a slightly different pattern. Fertilization increased the yields (10^3 kg/ha) in the 0.5 x 1 m spacing on both the FL and OF sites. Except for the 2 x 1 m spacing on the OF site, yields from fertilized seedling plots tended to be

Table 5.--Influence of land classification, initial spacing and fertilization on the dry matter production of black locust and sycamore plantations after one and two growing seasons. (Values presented as 10^3kg (metric tons)/ha.).

Land Classification	Spacing (m)	Black Locust Fertilized Year 1	Black Locust Fertilized Year 2	Black Locust Not Fert. Year 1	Black Locust Not Fert. Year 2	Sycamore Fertilized Year 1	Sycamore Fertilized Year 2	Sycamore Not Fert. Year 1	Sycamore Not Fert. Year 2
	.5 x 1	2.2	17.00^{b}[1]	1.62	22.70^{a}	.43	1.08^{a}	.36	.67^{ab}
Forest Land	1 x 1	1.1	11.80^{c}	.81	11.50^{c}	.22	.32^{b}	.18	.56^{ab}
	2 x 1	.6	8.90^{d}	.41	8.40^{d}	.11	.31^{b}	.09	.31^{b}
	.5 x 1	.24	3.90^{b}	.14	5.46^{a}	.20	1.06^{a}	.14	.53^{b}
Old Field	1 x 1	.12	2.91^{bc}	.07	.87^{c}	.10	.57^{b}	.07	.65^{b}
	2 x 1	.06	1.19^{c}	.04	.92^{c}	.50	.33^{bc}	.04	.12^{c}

[1] Row or column values for a given site species, and year not followed by the same letter are significantly different ($\alpha = .05$).

lower than those receiving no fertilizer. Again, the competing weed populations absorbed much of the added fertilizer, in effect negating this treatment, and became a more effective competitor for the remaining soil water and nutrients.

SUMMARY

Yield of short rotation biomass plantations can be significantly effected through species and site selection, variation in plantation density (stems/ha) and cultural practices including fertilization. High fiber yields may be obtained with proper species-site selection, but selection of an off-site species (in the case of this study, sycamore) may result in unacceptable yields no matter what cultural practices are included. Marginally productive forest lands may be used to establish biomass/silage plantations only with careful attention to species selection and intensive cultural treatments. Evaluations should be made of the economic soundness of such an undertaking.

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CONCENTRATION AND DISTRIBUTION OF SELECTED ELEMENTS IN ABOVEGROUND BIOMASS OF 8-YEAR-OLD SLASH PINE[1]

Eugene Shoulders[2]

Abstract.--Concentrations of nitrogen, phosphorus, potassium, and magnesium followed the general order foliage > small branches > bole bark ≥ large branches ≥ bole wood, with certain exceptions. Concentration of these nutrients in needles and branches decreased with distance from apical meristems and were usually less in lower than in upper crown tissue. Calcium concentration in needles and branches increased with distance from apical meristems and were lower in current foliage from the upper crown than in older foliage or branches. Stem bark contained a higher concentration of calcium than stem wood. Foliage comprised only 22 percent of the above-ground dry weight of the trees, but contained 35 to 56 percent of individual nutrients. Bole wood and bark accounted for 58 percent of the biomass and contained 31 to 41 percent of the nutrients.

INTRODUCTION

Researchers need a thorough understanding of the variation in the concentration of nutrients between plant parts if they are to devise procedures for accurately estimating nutrient contents of forest crops. Individual tree data from a site amelioration study on a level to slightly sloping flatwoods site in central Louisiana (Shoulders and McKee 1974) provide preliminary estimates of these variations in 8-year-old slash pine plantations. In this paper, I report concentrations of nitrogen, phosphorus, potassium, calcium, and magnesium in foliage, branches, and boles, and the effects of tissue age and crown position on them. I also report relative amounts of each nutrient in different classes of tissue. Finally, I consider implications of these results in sampling trees and stands for nutrient contents.

MATERIALS AND METHODS

Four sample trees were harvested from each of 12 slash pine plots. The trees were taken from the second and third rows from the exterior of the plot. One tree was selected at random on each side of the plots from among individuals whose boles were free of disease or deformity. Trees were cut in September after they had completed most of the current season's growth but before they had begun to shed their older needles. Sample trees ranged in diameter at breast height (dbh) from 7.6 to 14.2 cm and in total height from 6.07 to 9.05 m. Their dry weights ranged from 8.4 to 39.6 kg.

Aerial parts above a 7.5 cm stump were separated into bole, upper crown branches, and lower crown branches. Branches from the two crown positions were further subdivided into:

1. Needles of the current year.
2. Older needles.
3. Twigs and branches of the current year.
4. Older needle bearing branches.
5. Live branch sections devoid of needles.
6. Dead branches.

Dead branches and bare, live branch segments were present only in the lower crown.

Needle bearing portions of the upper stems were included with upper crown branches. Remaining portions of the boles were sectioned acropetally into 1.2-m-long bolts. Identities of all classes of material from each tree were preserved throughout harvest and subsequent analyses.

Bole material was subsampled by cutting a 3.5-cm-long disk from the base of each bolt. Each class of crown material was also subsampled.

Materials remaining after subsampling were dried to constant weight in a lumber kiln at about 70°C and weighed.

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

[2] Principal Silviculturist, Southern Forest Experiment Station, USDA Forest Service, Pineville, Louisiana. Drs. W. H. McKee, Jr. and B. F. McLemore designed the sampling procedure and collected the plant materials. Dr. McKee supervised laboratory analysis of the samples.

Subsample materials were ovendried to constant weight at 70°C after bark of bole samples was separated from wood. Subsample dry weights were added to those of the main sample. Weights of bark and wood in individual segments of the bole were computed from proportions in the subsamples. All subsample materials were ground to pass a 1.5-mm screen and their nutrient contents measured. Nitrogen was determined by the Kjeldahl method (Jackson, 1958). Other analyses were made on material dry-ashed for 2 hours at 450°C and taken up in 0.3N HNO_3. Phosphorus was determined by the molybdovanadate procedure (Jackson, 1958), and potassium, calcium, and magnesium by atomic absorption.

Total amounts of individual nutrients in the tree segments were computed. Proportions of each tree's weights and nutrient contents in every class of material were then determined.

Differences between treatments and tree segments in concentrations of nutrients and in proportion of the trees' total content were tested by analyses of variance and Duncan's new multiple range test with significance at the 0.05 level.

The site amelioration treatments (control, flat disking, and bedding) affected tree size but did not influence significantly the proportions of total weight in stem wood, stembark, branches, and needles (McKee and Shoulders 1974) or the concentration of nutrients in various plant parts. Therefore, results reported here are averages for 48 sample trees.

RESULTS

Concentrations of Nutrients in Tree Segments

Concentrations of nitrogen in tissues ranged from 0.144 to 0.792 percent, of phosphorus from 0.018 to 0.091 percent, of potassium from 0.028 to 0.606 percent, of calcium from 0.084 to 0.399 percent, and of magnesium from 0.039 to 0.123 percent (table 1). Except that dead limbs and non-needle bearing segments of live branches from the lower crown contained similar percentages of all nutrients, every plant part sampled differed significantly from every other in concentration of one or more elements.

Percentages of nitrogen, phosphorus, potassium, and magnesium were always significantly higher in needles than in the branch segments that bore them. In older tissues, calcium was also more abundant in needles than in branches. But current year needles and branch segments contained similar concentrations of calcium.

Levels of nitrogen, phosphorus, and potassium were higher and of calcium lower in current year needles and twigs from the upper crown than in similar tissues from the lower crown. Crown position did not affect magnesium levels in current foliage, but current year twigs from the upper crown contained higher percentages of magnesium than their lower crown counterparts.

In older needles and needle-bearing branch segments, crown position affected only potassium, calcium, and magnesium levels. Potassium was significantly higher and calcium significantly lower in upper crown needles and branches than in like tissues from the lower crown. Magnesium was less abundant in older needles from the upper than in older needles from the lower crown.

In the upper crown, current year needles and twigs contained higher concentrations of nitrogen, phosphorus, potassium and magnesium and lower concentrations of calcium than older needles and branches. Except for phosphorus in foliage, these differences were significant. Similar trends developed in lower crown tissues but differences were usually smaller and fewer of them were significant.

Older needle bearing branches from the lower crown had higher concentrations, usually significantly so, of nitrogen, phosphorus, potassium, and magnesium than dead limbs and non-needle-bearing branch segments of live branches. Calcium levels, however, tended to be lower in needle- than in non-needle bearing live branch segments. As noted earlier, non-needle bearing live branch segments and dead limbs contained similar concentrations of all nutrients.

No clear trend emerged in nutrient levels in bole wood or bole bark relative to height in the stem. These results apply only to portions of the bole devoid of needles, as needle bearing portions of the main stem were included with upper crown branches. In the needle bearing portion of the bole, concentrations of nitrogen, phosphorus, potassium, and magnesium probably increased and of calcium decreased with height.

Nutrient levels were higher in bark than in wood. Except for phosphorus, these differences were significant. Bark also contained higher concentrations of nitrogen and potassium than non-needle bearing live branch segments and of magnesium than all branch tissue except current-year twigs from the upper crown.

Stem wood resembled dead limbs and non-needle-bearing segments of live branches in concentrations of nitrogen, phosphorus, potassium, and magnesium. Calcium levels, however, were significantly lower in wood than in any other tissue.

Table 1.--Nutrient concentration in segments of the tree biomass from 8-year-old slash pine

Segment and Age	Nutrient concentration[1]				
	N	P	K	Ca	Mg
	Mg/g				
			Foliage		
Upper crown					
Current	7.92 ± .73g[2]	.91 ± .29f	6.06 ± 1.88h	1.59 ± .69b	1.15 ± .21e
Older	7.13 ± .81f	.88 ± .35ef	3.14 ± 1.29f	3.03 ± .80d	.93 ± .19d
Lower crown					
Current	7.21 ± .54f	.77 ± .25e	3.63 ± 1.07g	2.17 ± .68c	1.23 ± .16e
Older	7.02 ± .74f	.86 ± .40ef	2.04 ± .97de	3.99 ± 1.08e	1.19 ± .25e
			Branches		
Upper crown					
Current	2.93 ± .74e	.44 ± .16d	3.85 ± 1.43g	1.74 ± .64b	.82 ± .22c
Needle bearing, over 1-yr-old	2.07 ± .31c	.25 ± .12bc	1.73 ± .56cd	2.17 ± .61c	.69 ± .10b
Lower crown					
Current	2.30 ± .30d	.32 ± .12c	2.37 ± .98e	2.27 ± .73c	.69 ± .15b
Needle bearing, over 1-yr-old	1.97 ± .25c	.24 ± .13bc	1.20 ± .42b	3.00 ± .68d	.67 ± .15b
Non-needle bearing	1.46 ± .19a	.14 ± .08ab	.70 ± .59a	3.35 ± 1.06d	.43 ± .10a
Dead	1.61 ± .36ab	.10 ± .07a	.28 ± .34a	3.25 ± 1.33d	.39 ± .10a
			Bole		
Bark	1.74 ± .17b	.22 ± .07abc	1.39 ± .47bc	1.59 ± .48b	.90 ± .70cd
Wood	1.44 ± .22a	.18 ± .10ab	.66 ± .18a	.84 ± .31a	.42 ± .34a

[1] Values in any column with the same letter are not significantly different at the 0.05 level.

[2] Standard deviation for nutrient concentration in segment. Standard error of means may be derived by dividing Standard deviations by $\sqrt{48}$.

Amounts of Nutrients in Tree Segments

Foliage comprised only 22 percent of the aboveground biomass of these 8-year-old trees. But it contained 56 percent of the nitrogen, 54 percent of the phosphorus, 49 percent of the potassium, 35 percent of the calcium, and 39 percent of the magnesium in aerial parts (fig. 1). In contrast, wood and bark of the bole contained 58 percent of the trees' dry weights and only 31 to 42 percent of the aboveground nutrients. Twenty percent of the biomass was in limbs. They contained 14 percent of the nitrogen and phosphorus in the trees, 20 percent of the potassium, 30 percent of the calcium, and 19 percent of the magnesium.

Implications in Sampling

Coefficients of variation for nutrient concentrations in individual plant parts $\left(\frac{\text{standard deviation}}{\text{mean concentration}} \times 100\right)$ ranged from 7 percent for nitrogen in current needles from the lower crown to 121 percent for potassium in dead branches. Coefficients of variation for concentrations of individual nutrients in foliage and needle bearing branch segments did not exceed 55 percent. For these portions of the crown, a sample of 31 trees should estimate concentrations of all nutrients within ± 10 percent two-thirds of the time. For a 1-in-20 chance of error in sampling, 121 trees would be required. Samples of these sizes should estimate concentrations of nitrogen in current needles from the lower crown within ± 1.4 percent and concentrations of potassium in dead branches within ± 22 percent.

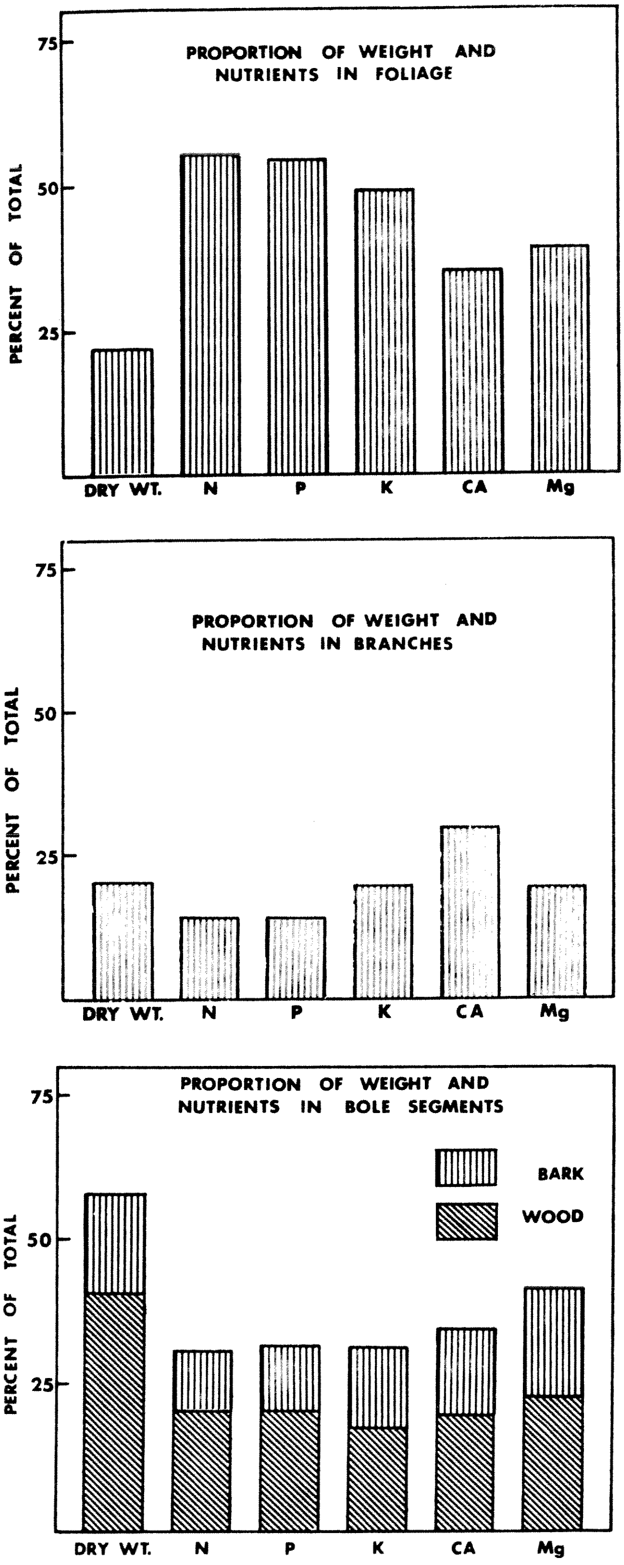

Figure 1--Distribution of weight and nutrients in aerial parts of 8-year-old slash pine trees.

DISCUSSION AND CONCLUSIONS

Obviously, data for 48 trees from one 8-year-old plantation are inadequate to characterize concentrations, amounts, or distribution of nutrients in aboveground tissues of slash pine trees. Concentrations of nutrients in tissues vary with soil fertility (Pritchett 1968, Ballard and Pritchett 1975) and soil moisture regime (White and Pritchett 1970, White et al. 1972). Work with other species (Wells and Metz 1963) and unpublished data from our laboratory show that concentrations in foliage vary seasonally. Site, age, and stand density affect proportions of nutrients in individual parts by altering the distribution of the total biomass among tissues (Metz and Wells, 1965, Rennie 1966, Switzer et al. 1968) and perhaps by affecting concentrations of nutrients in individual segments.

For the most part, the task of quantifying these relationships lies ahead. Data presented in this paper suggests that it will not be easy. Foliage, branches, bark, and wood differ greatly in nutrient concentrations. Within foliage and branches, concentrations vary with position in the crown and age of tissue. All these factors must be considered in devising a sampling scheme to estimate nutrient content of trees and stands.

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THE PATTERN OF NATURAL REGENERATION AND HEIGHT STRATIFICATION WITHIN A NATURALLY-CREATED OPENING IN AN ALL-AGED PIEDMONT DECIDUOUS FOREST[1][3]

James N. Skeen[2][4]

Abstract.--Detailed species inventories over a 4-year period within a natural opening created by a combination of storm damage, pine beetle damage, and windthrow in an old-growth Piedmont deciduous forest revealed distinct patterns of species density shifts, species regeneration and survival, and height stratification. Between 4 and 7 years after canopy opening relative densities of loblolly pine and yellow-poplar decreased markedly. Relative densities increased moderately among black cherry, sweetgum, and flowering dogwood and increased markedly among the oaks and hickories. By the end of the seventh growing season a distinct pattern of height stratification was evident. Above 160 cm loblolly pine, sweetgum, and flowering dogwood were dominant in a 2:1:1 ratio. Between 51-160 cm loblolly pine, black cherry, sweetgum and flowering dogwood were dominant in a 4:2:1:1 ratio. Between 11-50 cm black cherry, sweetgum, and various oaks were dominant in a 3:1:1 ratio. The lowest stratum, 10 cm and below, was dominated by black cherry, various oaks, and various hickories (2:1:1 ratio).

INTRODUCTION

The forests of the southeastern Piedmont, like the deciduous forests of eastern North America in general, are four-tiered communities comprised of herbaceous groundcover, shrubs, and subcanopy and canopy arborescent strata. Despite this widespread and readily apparent vertical structure, there has been little emphasis on determining how early in the developmental sequence of temperate deciduous forests this stratification occurs and its possible influences on community regeneration dynamics (e.g., differential germination, survival and mortality, and eventual establishment). As Smith (1973) noted, there has been almost no critical or systematic examination of processes of stratal development within forest communities.

Contemporary viewpoints on natural regeneration in temperate deciduous forests have derived from the early work of Jones (1945), Watt (1947), and Bray (1956). Natural regeneration consequently is viewed by many workers as the cyclical species replacements occurring within openings or "gaps" occasionally created in the forest by natural events, sometimes catastrophic and spectacular, sometimes relatively minor and more subtle (Forcier 1975, Fox 1977, Brewer and Merritt 1978, Barden 1979, Ehrenfeld 1980). Windthrow, glaze storms, and occasional insect infestations are major causes of gap formation on the southeastern Piedmont. Less spectacular but probably equally important is the death and fall of trees from the rigors of age such as fungal and/or viral pathogens. The main focus in most studies of gaps has been

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on the sequence of species shifts or on the ultimate stand composition that results within such openings over long timespans.

For example, several studies were conducted following the loss of the American chesnut (Castanea dentata (Marsh.) Borkh.) from the forests of eastern North America. These studies emphasized species replacements and shifts in community composition among various forests of the region (Keever 1953, Nelson 1955, Mackey and Sivec 1973, Stephenson 1974). Other studies of gaps and openings have assessed and evaluated various silvicultural practices, particularly clearcutting or seed tree cutting (Wendel 1975, McGee and Hooper 1975, Johnson and Krinard 1976). Other studies have been conducted to quantify the early colonization and short- and intermediate-term survival of woody species within canopy gaps (Skeen 1976) or the response of understory species following natural creation of different-sized gaps (Ehrenfeld 1980). A central premise in all these studies, either expressed or implied, has been that the resulting forest community is a mosaic or patchwork of abutting or overlapping gaps created at different times. In these gaps most trees would have initiated in a few years following gap creation. On a larger-than-gap-size scale, the resulting forest generally appears as a mixture of trees of many species having different ages and (usually) different sizes--the classical "all-aged" forest. Oliver (1980) recently has suggested that mixed-species forests in the eastern and northwestern United States, particularly after management manipulations creating large openings, may develop essentially even-age patterns internally. These forests may exhibit a deceptive vertical stratification that could appear all-aged to the casual observer. Consequently, a knowledge of past management practices, natural species replacement/regeneration sequences and patterns of vertical sorting between species during the stand's developmental stages may be imperative in prescribing appropriate management practices.

Opening size has been repeatedly stressed as an important determinant affecting regeneration, survival, establishment, height growth pattern, and eventual species composition in forest gaps (Jones 1945, Jackson 1959, Ehrenfeld 1980). But no detailed study has appeared that considers the vertical stratification within gaps in the early years after canopy opening. The sheltering effect of such internal gap development probably ameliorates gap microclimate and may possibly exert as great a controlling influence on internal gap species dynamics as does gap size, proximity to seed sources, surrounding canopy height, etc.

Understanding gap dynamics and patterns of internal forest development requires documenting and quantifying the pattern and sequence of changes in species composition, survival/mortality, and establishment during the early stages of natural regeneration. Equally important--particularly in view of Oliver's recent (1980) contentions--is consideration of questions regarding early vertical stratification in canopy gaps: Is vertical pattern apparent in the early years of gap phase replacement; if so, how early does it occur in the developmental/regeneration sequence? If pattern occurs--if there are two or more well-defined layers--are there compositional differences between the layers; if so, can the component species' silvicultural traits account for the pattern(s) observed? From the existing species mix and any early vertical pattern observed, does it appear likely that the vertical structure will increase or diminish in complexity; are species seemingly being lost or replaced as dominants? The major aim of the present study--a part of a larger, long-range effort--was to gather and evaluate data which might suggest answers to these and related questions.

SITE CHARACTERISTICS AND STUDY PLAN

Obviously attempts to formulate answers to these and similar questions could be made from data derived from studies following either of two basic approaches--either the detailed study of multiple gaps of different ages at a single point in time, or the intensive study of a single gap over many years. This study has followed the latter approach.

Site Characteristics

The study gap was in Fernbank Forest, a metropolitan Atlanta (33°46'N, 85°19'W) woodland of 25 ha. The forest has been described as a relatively mature hardwood forest (Skeen 1974) and, more recently, as a remnant (Wharton 1978) or relict (Dew 1980) of what original Piedmont forests on favorable sites may have been like. The forest would be termed a bluff-ravine forest with northern affinites according to the classification of Wharton (1978) and a north-facing bluff forest after the Piedmont forest classification of Oosting (1942). It lies within the Atlantic slope section of the Oak-Pine Forest region described by Braun (1950) and most closely approximates SAF cover-type 59 (yellow-poplar--white oak--northern red oak) (Society of American Foresters 1964). Canopy dominants, in order of decreasing importance, include yellow-poplar (Liriodendron tulipifera L.), white oak (Quercus alba L.), hickory (Carya glabra (Mill.)/C. tomentosa (Nutt.)/C. cordiformis (Wang.) K. Koch), northern red oak (Quercus rubra L.) and American beech (Fagus grandifolia Ehrh.) (Skeen 1974, Dew 1980). Mature pines (Pinus taeda L./P. echinata Mill.) have decreased in canopy importance since a severe southern pine beetle epidemic over the area in the early 1970's but are still highly visible and important canopy members. Tree density (>10.2 cm d.b.h.) within the forest is 447 trees/ha, basal area coverage is almost 38 m^2/ha, and above-ground biomass has been estimated as approximately 356 mt/ha (Skeen 1974).

Windthrow, glaze storm damage, and pine beetle damage have been severe in certain parts of the forest and have caused many canopy openings--some single-tree gaps and others multiple-tree gaps. Natural regeneration of both pine and hardwoods is now occurring in these openings. The site studied was one of the larger of these gaps (two or more canopy hardwoods have been lost 9-19 years ago and a single pine lost during the early 1970's beetle infestation). The rectangular clearing lay approximately 30 m inside the eastern boundary of the woodland and extended approximately 25 m east-west and about 15 m north-south. A predominantly deciduous canopy (25-30 m in height) bordered the clearing. Site elevation was approximately 340 m above mean sea level and the slope was approximately 5 percent facing southwest.

Methods

In early 1974 the 375 m^2 opening (25 m by 15 m) was subdivided into a permanently-marked grid network of 125 3 m by 1 m plots. The easternmost two-thirds of the opening (83 3 m by 1 m quadrats) was well along in the early stages of hardwood succession and was dominated by saplings grading, at that time, to about 5 m in height. The history of the origin and later regeneration of this older portion of the area could not be documented with certainty so initial attentions were focused on the younger, then pine-dominated, portion of the opening (42 3 m by 1 m quadrats). Spring/summer 1971 was the first growing season (year 1) for the younger portion of the opening.

Between mid-March and late May 1974 (early in growing season 4) a complete census was made of woody individuals present in the 42 3 m^2 quadrats comprising the most recently colonized area. Each woody individual present, regardless of size, was assigned an identifying number and was individually marked with an aluminum tag. Seedling and sapling categories were not differentiated by height classes in the initial census except to note new seedlings of the current year. The area was maintained free of outside disturbance, and the census was repeated in early March 1976 and late June 1977. Individuals that died between censuses were noted and new individuals which had appeared during the time interval were numbered and marked. Height measurements were also recorded during the 1977 census. The annual pattern of groundlevel global radiation in the opening was documented during the early colonization/establishment phase (mid-1974 to mid-1975) (March and Skeen 1976) and the near-ground (0-75 cm aboveground) thermal regimen--especially that following intense summer thunderstorms--was documented during the summer of 1974 (Skeen and March 1977). From the data obtained it has been possible to document the regeneration dynamics (early colonization, survival/mortality, establishment, etc.) that have occurred at 3 intervals during the first 7 years of colonization and re-establishment within the gap. The pattern of height growth occurring within the area by the end of the 7 years was recorded as well.

RESULTS

The inventories conducted early in the fourth (1974) and sixth (1976) growing seasons and midway through the seventh (1977) growing season revealed 18, 19, and 21 species-groups respectively (Oak and hickory designations consisted of multiple species, mostly indeterminable during early growth.). Throughout the three censuses, seven species-groups accounted for about 90 percent of the total number of individuals (93 percent, 91 percent, and 88 percent in 1974, 1976, and 1977) and were never represented by fewer than 9 individuals (absolute density of 714 stems/ha). These species-groups were loblolly pine (Pinus taeda L.), black cherry (Prunus serotina Ehrh.), tulip or yellow-poplar (Liriodendron tulipifera L.), sweetgum (Liquidambar styraciflua L.), flowering dogwood (Cornus florida L.), the hickories (Carya spp.), and the oaks (Quercus spp.). Other less important but frequently occurring species included red mulberry (Morus rubra L.), black gum (Nyssa sylvatica Marsh.), southern magnolia (exotic encroachment from residential plantings in the area) (Magnolia grandiflora L.), redbud (Cercis canadensis L.), and hawthorn (Crataegus sp.).

Density Relationships

The absolute density of individuals was approximately 43900 stems/ha in the 1974 census, 34800 stems/ha in the 1976 census, and 33400 stems/ha in the 1977 census. Figure 1 depicts the relative density or percentage composition attributable to each of the seven major species-groups at each census period. By the seventh growing season loblolly pine and yellow-poplar decreased markedly in relative density (38 percent

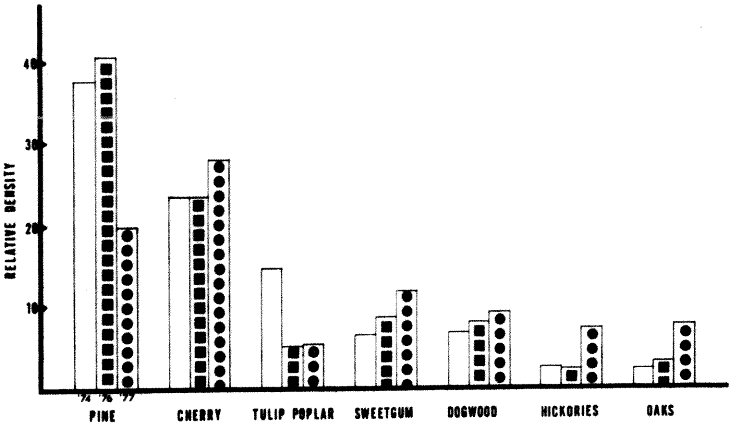

Figure 1.--Relative densities (percentage composition) of the seven most prominent species-groups early in year 4 (1974), early in year 6 (1976), and midway through year 7 (1977) after canopy opening.

to 20 percent, and 15 percent to 5 percent, respectively). Conversely, black cherry, sweetgum, and flowering dogwood increased moderately in relative densities over the timespan (24 percent to 28 percent, 7 percent to 12 percent, and 7 percent to 9 percent, respectively). The oaks and hickories, while making similar percentage gains, increased markedly in relative community composition (2 percent to 8 percent, and 2 percent to 7 percent, respectively), exhibiting a nearly four-fold increase in each instance.

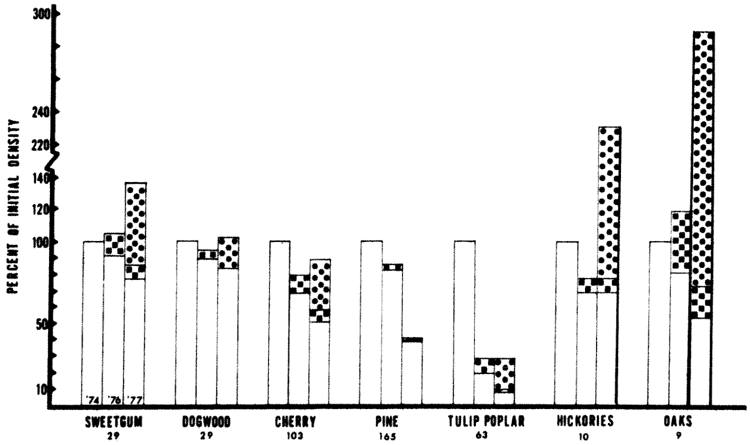

Figure 2.--Changes in densities within the seven most prominent species-groups over 3 years (1974-1977). All comparisons are made against respective species-group census values of the first census year (1974, year 4). Open bars represent the fates of original census individuals in subsequent years; square-stippled bars represent the fates of colonizers from the 1974-76 interval censused in 1976; and dot-stippled bars represent the colonizers from the 1976-77 interval censused in 1977. Values appearing below each species-group name represent the number of individuals within each group enumerated in the original (1974) census.

Reasons for these species shifts are apparent in Figure 2. It shows the survivorship over time of the original (year 4) population of each species plus new colonizers occurring within each subsequent census interval and their survival expressed as a fraction of each species' original population density. Employing the original census count for each species as a basis of comparison and expressing all subsequent regeneration, survival, and establishment relative to this base value clarified whether a species population was increasing or declining. Causal factors such as high (or low) survival of the initial population or possibly subsequent colonization and survival as determinants of the shifts in relative densities also became apparent. For example, the decrease in loblolly pine relative density is due to a survival of the original population of less than 40 percent by year 7 coupled with both very low regeneration and very low survival of new colonizers in the time interval between years 4 and 7 (Figure 2). Similarly, less than 8 percent of the original (year 4) yellow-poplar population survived until year 7; new colonization and its survival over the interval was sufficient, however, to stabilize the yellow-poplar population at slightly less than 28 percent of its initial (year 4) level. Although black cherry, sweetgum, and flowering dogwood are increasing in terms of relative community proportion, only sweetgum and dogwood are increasing in terms of absolute numbers of individuals relative to the original (year 4) census (Figure 2). The marked increase in the hickories and oaks is due to moderately high survival of the original populations (69 percent and 55 percent respectively) coupled with very high colonization for both species between years 6 and 7.

Height Stratification

Figure 3 shows the pattern of aboveground stratification of woody species at the third census date (midway through the seventh growing season) after canopy opening (1977). Each species-group symbol shown represents an approximage density of 300 stems/ha. This profile diagram coupled with frequency histograms by height of each species-group suggested the occurrence of at least four strata. For this study these were set at 0-10 cm aboveground, 11-50 cm aboveground, 51-160 cm aboveground, and individuals greater than 160 cm aboveground.

Figure 4 reflects stratification recognizable within each species-group (narrow, patterned bars) as well as the vertical sorting by species-group within the community as a whole (wide, solid bars). Pines and dogwoods, for example, are most often encountered in the 51-160 cm stratum (narrow, patterned bars) while black cherry, yellow-poplar, sweetgum, and the oaks are most commonly encountered in the 11-50 cm stratum. The hickories are most often found in the lowest (0-10 cm) layer. If each height or stratum is considered individually (wide, solid bars), pines dominated the level above 160 cm with sweetgum and flowering dogwood also prominent (2:1:1 ratio). Between 51-160 cm in height, loblolly pine, black cherry, sweetgum, and dogwood occurred in a 4:2:1:1 ratio. Between 11-50 cm black cherry, sweetgum, and various oaks occurred in a 3:1:1 ratio with all other species-groups also represented in smaller proportions. The lowest stratum, 10 cm and below, was dominated

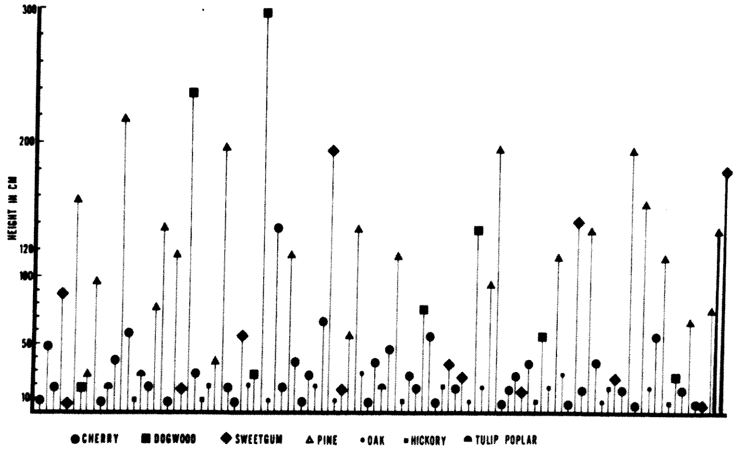

Figure 3.--Profile diagram of height stratification pattern in 126 m^2 clearing 7 years after canopy opening. Each symbol represents approximately 300 stems/ha (total stand density: 33400 stems/ha).

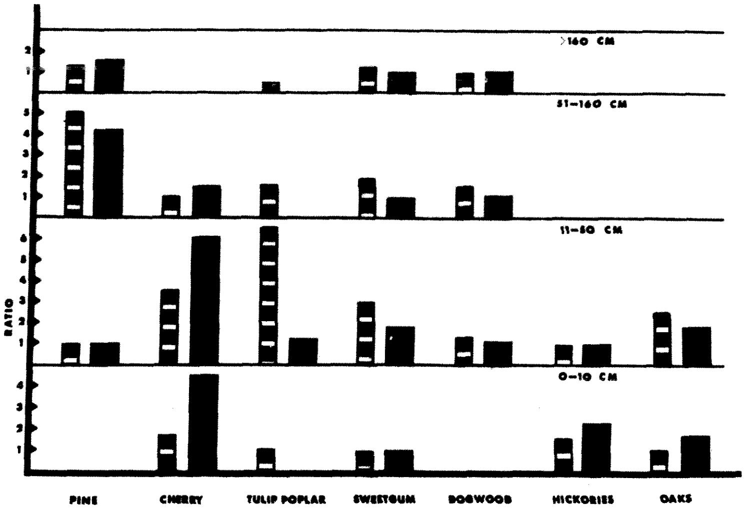

Figure 4.--Patterns of height distribution within each respective species-group (narrow, patterned bars) and species distributions within each stratum (wide, solid bars). (Narrow, patterned bars should be compared vertically within a single species-group; wide, solid bars should be compared horizontally within a single stratum.)

by black cherry, various oaks, various hickories, and sweetgum in a 5:2:2:1 ration. Thus pine and dogwood were essentially absent from the lowest (0-10 cm) stratum, all species-groups were well represented in the 11-50 cm stratum, oaks and hickories were essentially absent from the uppermost two strata (>51 cm), and black cherry was not encountered in the uppermost stratum (>160 cm).

DISCUSSION

Density Relationships

The density levels encountered in the year 4, year 6, and year 7 censuses (4.4 stems/m^2, 3.5 stems/m^2, and 3.3 stems/m^2, respectively) are within reasonable expectations (Skeen 1976) given the energy regimen within the clearing in the early years of colonization (March and Skeen 1976). Although most previously reported woody stem densities in natural forest regeneration studies have ranged between 1 and 2 stems/m^2 (Skeen 1976), such values generally have been obtained under well-developed forest canopies, not in canopy gaps. The present data suggest that decreasing stem densities occur with increasing vertical stratification and canopy closure (and with the consequent reduction of light intensities near ground level).

The shifts in relative densities observed largely parallel classical interpretations of the component species' tolerance to shade with the most intolerant species (loblolly pine and tulip poplar, according to classical tolerances regimes) decreasing markedly in community importance. The more shade-tolerant oaks and hickories exhibited a pronounced increase in community importance. Dogwood, the most shade-tolerant of the component species, did not appear to be undergoing a pronounced shift toward increasing relative density and community importance. Such a response might be expected if shade tolerance alone were the main determinant of early species success. There are several likely reasons for this paradox. There was no significant dogwood component in the lowest (0-10 cm) stratum (Figure 4). This suggests little or no continuing seedling production or seedling survival by dogwood; this contention is substantiated by Figure 2 which indicates very low seedling regeneration in both 1976 and 1977. Further, none of the seedlings produced in 1976 survived until 1977. This suggests that most of the dogwoods in the community are of vegetative origin. This suggestion is supported both by recent field observation at the study site and by dogwood's well-known tendency to reproduce vegetatively (Fowells 1965). It is likely that many of the dogwoods recorded in the upper three strata originated from sprouts and that at least the uppermost individuals were responding initially to release. Further, if most or many of the original stems were in fact of sprout origin, the relative density of dogwood likely was overestimated since each stem was considered an individual plant and was enumerated and weighted equally.

The pattern of tulip poplar, generally considered a pioneer hardwood in the Southeast--but recently suggested as a component of climax or old-growth communities as well (Buckner and McCracken 1978; Skeen, Carter and Ragsdale 1980)--is also perplexing. Although the low survival encountered may be partially an artifact of difference in sampling season (early growing season in 1974, 1976; mid-season in 1977) as noted previously (Skeen 1976), our present understanding of tulip poplar's behavior is inadequate to explain (1) the continuing pronounced decline in survival of the original (1974) colonizers during later census intervals, (2) the determinants controlling sufficient regeneration to maintain the population at a relatively stable level (ca. 28 percent of initial density, 5 percent community relative density), and (3) how and when tulip poplar assumes sufficient prominence in the successional sequence to eventually become the most highly important species in the community (Skeen et al. 1980).

Although the oaks and hickories, relatively shade-tolerant community members, exhibited the most striking density shifts (Figures 1, 2), their absolute population densities were initially the lowest of the major species-groups. Consequently, on a comparative basis, a relatively modest increase in absolute density would lead to a many-fold increase on a relative basis. This was the case in the present study.

Vertical Pattern

Well-defined and highly structured vertical pattern occurs as early as year 7 after canopy opening. The questions remaining then become: (1) does measurable well-defined stratification possibly occur even earlier in the community's redevelopment sequence; (2) how many layers can be demonstrated; (3) are compositional differences evident between layers, and, (4) are ongoing species shifts apparent at the different levels? Without earlier height measurements it is impossible to tell whether well-defined vertical stratification does occur earlier than the seventh growing season. At least 4 strata can be easily demonstrated by year 7 (Figures 3, 4). Argument could be made for further subdividing the 51-160 cm stratum into two components--51-100 cm and 101-160 cm. The four well-defined strata emphasized seem adequate, however, for documenting vertical structure at this point of community development. Definite compositional differences occur between the respective strata (Figure 4)--each lower level is not merely a later-initiating layer with similar species composition to the next higher (and presumably earlier-initiating) stratum. The uppermost layer was dominated by loblolly pine, sweetgum, and dogwood (2:1:1 ratio). Observational evidence suggests that the pines are of seedling origin and that the dogwoods are mainly of vegetative origin and (at least the older and taller individuals) were released from suppression at the time of gap formation. The situation with regard to sweetgum is unclear. (Sweetgum's silvicultural traits encompass both possible seed and sprout origins, and both initiation at gap formation and from advance regeneration released from suppression.) The next lower level (51-160 cm) was dominated by the same three species--likely of similar origins--plus black cherry, probably of seedling origin. The next lower level (11-50 cm) was the most diverse and contained individuals of all seven species-groups. The relatively shade-tolerant oaks and hickories appeared in this level for the first time, a circumstance suggesting delayed initiation and/or slow growth. The lowest level (0-10 cm) lacked pine and dogwood and had no noteworthy tulip poplar indicating that these three species were no longer reproducing in the opening. Evidently, species shifts are occurring between the different levels with oaks and hickories yet to reach the uppermost strata and pines, dogwoods, and tulip poplars gradually disappearing from the lowermost. Such shifts closely parallel these species' classically-interpreted tolerance requirements with intolerant species gradually being replaced by more tolerant species.

Community Development Regime

In recent years several attempts have been made to reduce the continuous and highly integrated processes that occur during secondary succession or community development to generalized patterns that might allow inferences to be made about community origins, likely directional changes during development, and various properties (e.g., composition, stability) of the eventual end-state community (Goff 1968, Marks 1974, Forcier 1975, Connell and Slayter 1977, Fox 1977, Oliver and Stephens 1977). While these attempts have fostered critical thinking and stimulated important questioning about causes, directionality, and processes associated with community development, they have sometimes proven difficult to reconcile with observations made and data obtained in the field, especially if only a short time in the overall successional sequence is involved.

For example, Goff in 1968 introduced the ideas, later amplified by Auclair and Cottam (1971), of general compositional change versus gradient (successional) compositional change. General compositional change has been interpreted as species replacement principally dependent on differences in growth rate, mortality, etc., between species and generally irrespective of the particular species' environmental responses. Gradient compositional change has been understood as compositional shifts in response to specific ecological gradients. Great difficulty exists, however, in attempting to interpret the present data while divorcing such factors as height patterns, differential survivorship, etc., from the possibly controlling influences of environmental (light, temperature, moisture, etc.) gradients.

More closely allied to the patterns, processes, and problems of gap re-colonization addressed here are the response patterns suggested by Marks (1974) for forest ecosystems that have been subjected to distrubances of some sort. These patterns have subsequently come to be known as the "reorganization" response pattern in which vegetation established prior to the disturbance is structurally reorganized (e.g., canopy encroachment/crown compensation, epicormic branch formation, suckering, release of advance reproduction), and the "new establishment" response pattern which mainly concerns vegetation newly established (e.g., by direct seeding into gap or germination of dormant seeds already in place) after the disturbance. Ehrenfeld (1980) recently tested these ideas experimentally in a gypsy moth-defoliated forest in New Jersey in an attempt to determine whether gap size was critical in eliciting one response pattern as opposed to the other. She suggested that tolerance is a highly important determinant of community compositional shifts regardless of which pattern is encountered. Species more tolerant than those of the interrupted canopy are likely to emerge as dominant in the "reorganization" pattern and species less tolerant than those of the disrupted canopy are likely to emerge as dominant (at least for a time) if the "new establishment" pattern is followed. It is difficult at this early stage of community development to reconcile the present data and patterns as strictly supportive of one or the other of these two disturbance response patterns. However, both the shift in relative density documented and the pattern of height stratification (and apparent species replacements) noted parallel the classically-interpreted tolerance regime of intolerant species being replaced by more tolerant species. This pattern is suggestive, at least at this time, of the "new establishment" response pattern.

Both implicit in and complementary to the preceding ideas regarding general vs. gradient compositional change and "new establishment" vs. "reorganization" response patterns are the ideas set forth by Forcier (1975). He emphasized the importance of differences in reproductive strategies between co-occuring species in determining both intermediate and ultimate compositional patterns during successional/developmental sequences. Seed mobility, whether an initial or secondary colonizer, growth rate, and the potentiality to reproduce vegetatively were characteristics utilized to differentiate tolerant, slow-growing, stable species from opportunistic rapidly-growing species. A different experimental design with entirely different aims and objectives would be necessary to definitively categorize the species of the present canopy gap according to reproductive strategy patterns or gradients. Subjective observations coupled with a knowledge of the individual species' silvicultural traits suggest however that the prominent co-occuring species-groups express a diversity of reproductive strategies, both opportunistic and tolerant. Such a diversity of reproductive strategies doubtless greatly influences both the patterns of species co-occurrence and the eventual species replacements noted.

Connell and Slayter (1977) proposed three alternative models of compositional change occurring during succession or community development. The first model, paralleling the "relay floristics" idea of Egler (1954) has been termed the "facilitation" model and suggests that entry, establishment, and success of later species is dependent upon early species modifying the site in some fashion. This model was suggested as applying primarily, among plant communities, to certain cases of primary succession. The secondary successional models, paralleling the "initial floristic composition" idea of Egler (1954) have been termed the "tolerance" model and the "inhibition" model. The "tolerance" model suggests that species sequence occurs as a result of species having developed different strategies for exploiting community resources. Later-occuring species can supposedly tolerate lower levels of resources than earlier species and can consequently grow to maturity in the presence of their predecessors. The "inhibition" model holds that all species resist invasions of competitors and that the initial colonizers will occupy the available growing space. This spatial filling effectively excludes later colonizers until the death or injury of initial colonizers releases space and community resources for utilization by successors. This latter model, the inhibition model, was supported by Connell and Slayter's reasonings as the pattern most likely to be encountered during secondary succession in terrestrial ecosystems. In the absence of detailed measurements on site modifications by colonizing species and interspecies influences--lacking in virtually all regeneration investigations to date--it is conjectural to attempt to ascribe the present species-group behaviors as confirming one or another of the Connell-Slayter models. Argument could be made that all three models are likely operative--though not necessarily contemporaneously--in the early development sequence at the present site.

Also based on the ideas of Egler (1954) are the concepts of autogenic vs. allogenic succession elaborated by Oliver and Stephens (1977). Autogenic succession, analogous to the "relay floristics" idea mentioned previously (Egler 1954), is essentially a tolerance regime with increasingly more tolerant trees being recruited to the understory and a few old survivors eventually establishing in the overstory. Allogenic succession (Egler's "initial floristic composition") is essentially a disturbance/competition regime with available growing space and resources as the determinants of eventual canopy success. Oliver and Stephens (1977) suggested that in old-growth forest ecosystems the allogenic pattern of succession is likely of principal importance. The corollaries to this pattern are: (1) most trees in old-growth forests will initiate soon after major disturbances of some sort; (2) these disturbance-affected forests are consequently comprised of a mosaic of small stands, each of which begins following major disturbance; and, (3) the dominant canopy is comprised of a broad range of ages, the older members likely released from previous suppression and the younger dominants never having been suppressed. Allogenic succession, as elaborated here, results in a gap-phase pattern of spatial distribution (as opposed to a regular pattern of spatial organization associated with autogenic succession). Although the data of the present study did not consider age and spatial distributions for the forest as a whole--and therefore cannot definitively substantiate the existence of an allogenic successional pattern at the present site--observations and additional sampling conducted throughout the forest in the course of other studies are highly supportive of the allogenic pattern.

Fox (1977), in a study of the rates and mechanisms affecting species replacements in forest communities leading to cyclical species alternations, suggested that eventual species replacement is largely influenced by seedling microhabitat. The seedling microhabitat is in turn largely controlled by 1-few dominant trees at a given point and time. This local density and compositional regulation--brought about by highly localized biotic and abiotic habitat modification--controls the cyclical dynamics and suggests a coupling of the "facilitation" and "inhibition" models (sensu Connell and Slayter 1977) discussed previously. The pattern of species shifts that seems to be initiating at the present study site (decline in loblolly pine/yellow-poplar prominence, increase in oak-hickory prominence) could be interpreted as the possible first stage(s) in the formation of a pine/yellow-poplar canopy which might be replaced (depending on growth rates, longevity, survivorship/mortality, etc.) eventually by an oak-hickory canopy. Such a pattern, if verified by subsequent long-term observation, would corroborate the pattern of cyclical species alternations in the present stand.

Categorization and classification of patterns resulting from the continuous and highly integrated processes which occur during secondary succession/community development in forest ecosystems are of limited direct utility when applied to observations made or data gathered over a few-year time interval. Such generalizations and simplifications of complex, integrated community responses are valuable starting points however in planning subsequent studies. They allow important and testable hypotheses to be formulated regarding mechanisms and causality underlying observed and implied patterns.

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STAND DEVELOPMENT FOLLOWING TWO TYPES OF CLEARCUTTING FOR DEER AND TIMBER PRODUCTION[1]

Jack A. Muncy and Edward Buckner[2]

Abstract. -- One year after harvesting there was no significant difference in the composition and structure of the regeneration that became established following complete (all stems over 6 feet high) and diameter limit (3 inches) clearcuts. Typical pioneer species, such as shortleaf pine and yellow-poplar, were largely absent.

Most of the regeneration was sprouts; old seedlings were of secondary importance and new seedlings comprised only a small portion of the regeneration mix. Species and diameter (or age) were the primary factors affecting sprouting characteristics. Basal and stump sprouts were the predominant sprout types for all size classes; root sprouts were common only for small diameter trees.

Regeneration following complete clearcutting appears to have a better chance for rapid development as the small diameter trees left following diameter limit clearcutting are responding to release and will soon compete strongly with new regeneration. Many leave-trees in the diameter limit treatment were damaged during logging and most are undesirable species for timber production.

Logging slash may protect regeneration from deer browsing. Deer exclosures will permit evaluation of their influence in future inventories.

INTRODUCTION[3]

A primary concern in developing timber cutting prescriptions for wildlife management units is maintaining a high-quality wildlife habitat in balance with secondary multiple use objectives. Effective management requires an understanding of the effects of various cultural techniques (cutting methods, prescribed fire, etc.) on the composition, quality, quantity, and availability (over time) of wildlife food and cover and on secondary multiple use objectives, such as timber production.

Clearcutting of hardwoods has been widely used to maintain browse within reach of deer (_Odocileus virginianus_). Regrowth following clearcutting generally provides abundant deer browse for three to four years after which stem terminals grow beyond the reach of deer and stand closure results in the natural pruning of lower limbs. Ten to 12 years after clearcutting there is generally little browse available. Burning two to three years after clearcutting may prolong the period of browse availability.

This study was the second (validation) phase of a project designed to develop a computer model simulating the composition and development of forest stands following clearcutting. Its purpose was to provide field documentation of the effects of complete and diameter limit clearcuts on the composition and structure of regeneration as validation information for an independently derived stand succession computer model developed as Phase I.

STUDY AREA

The Catoosa Wildlife Management Area (CWMA) near Crossville, Tennessee is the largest (80,000

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acres) wildlife management unit managed by the Tennessee Wildlife Resources Agency (TWRA). It is managed under the multiple use concept with deer production the primary objective; timber harvesting is secondary.

This part of the Cumberland Plateau comprises the Southwest Section of the Appalachian Plateau Physiographic Province. In Tennessee it contains approximately 3 million acres that are 75 percent forested.

The soils are the well drained Hartsells and Lonewood series which are very strongly to strongly acid throughout all horizons (Elder, 1977). Low soil fertility characterizes both series. The topography is level to gently rolling and the elevation is 1,700 to 1,760 feet. The climate is characterized by cool winters and mild summers, with a monthly mean temperature range from 35 degrees (F) in January to 73 degrees in July and 57 inches annual precipitation.

Oak-dominated forests that best fit the Society of American Foresters (SAF 1964) Type 41-Scarlet Oak (in the Oak-Hickory Type Group) are characteristic of this section of the Cumberland Plateau. Their seral position approaches climax on dry soils. This type has many variants due to the large number of associated species. In the study area these include the dry phase oaks, particularly post, (Quercus stellata Wangenh.), southern red (Quercus falcata Michx.) and black (Quercus velutina Larn.).

Prior to the establishment of the CWMA these stands were logged and periodically burned. American chestnut (Castanea dentata Marsh.) and chinquapin (Castanea pumila Mill.) sprouts occurred in both study areas suggesting the former presence of large trees.

Stand age was approximately 65 years for the dominant canopy trees although several age classes were represented in the heterogenous stand structure. Most of the large trees contained rot due to the frequent fires that characterized this section of the Cumberland Plateau prior to the mid-1950's.

METHODS

Two study areas (each approximately 40 acres in size) were selected as "typical" for upland sites on the CWMA. Principal component analysis (PCA) (Isebrands and Crow 1975) indicated that the two study areas were similar, with understory differences accounting for most of the variation.

On each area the following treatment plots (10 acres) were established: 1) a diameter limit clearcut removing all stems down to 3 inches dbh (following guidelines previously established by the Tennessee Wildlife Resources Agency for this area), 2) a complete clearcut in which all trees over 6 feet high were either harvested or felled, and 3) a control in which there was no cutting. Each of these main treatment plots were subdivided into burned and unburned subplots (5 acres). Subplots are to be burned once regeneration in the cut areas begins to grow out of reach of deer.

On each of the 5-acre subplots, 9 systematically arranged sample points were established providing plot center for concentric plots on which a pre-harvest inventory was made of: 1) merchantable timber (11.0 inches dbh and greater) on 1/5-acre plots, 2) pulpwood (stems between 3.0-10.9 inches dbh) on 1/20-acre plots, 3) sapling (stems between 6 feet high-2.9 inches dbh) on 1/40-acre plots, and 4) regeneration (stems less than 6 feet high) on 1/100-acre plots.

Logging of merchantable timber was accomplished in the fall, winter, and spring of 1978-79. A follow-up operation assured the cutting of all stems greater than 3 inches dbh on the diameter limit clearcut areas, and all stems over 6 feet high on the complete clearcuts. Twenty-four deer and rabbit (Sylvilagus floridanus) exclosures, each covering one-fortieth of an acre were erected to monitor the influence of browsing on regeneration and stand development. After one growing season, a post-harvest inventory was made to characterize the composition and character of the initial stands that developed following cutting. Periodic re-inventories will trace stand development under the various study conditions.

RESULTS AND DISCUSSION

Since, after one year, there were no statistically significant compositional differences between the stands developing following the two cutting methods, regeneration data for both treatments were combined and a single stand characterized (Table 1).

Regeneration

Regeneration (less than 6 feet high) in the two clearcuts averaged 4,945 stems per acre, of which 35 percent was oak, 34 percent other potential overstory hardwoods, 30 percent understory hardwoods, and 1 percent pine. Of these, 2,754 stems (56 percent) were sprouts (sprout clumps were counted as single stems), 1,295 stems (26 percent) were old seedlings (advanced regeneration), and 896 stems (18 percent) were new seedlings.

There was adequate regeneration of species suitable for both timber production and wildlife foods. However, common pioneer species for this region such as Virginia pine (Pinus virginiana Mill.), shortleaf pine (Pinus echinata Mill.) and yellow-poplar (Liriodendron tulipifera L.) were essentially absent. Except for a few Virginia pines, these trees were not present in the stands harvested. Although Virginia pine was harvested

TABLE 1

REGENERATION ONE YEAR AFTER CLEARCUTTING (BOTH TREATMENTS COMBINED)

Species	Old Seedlings		Sprouts		New Seedlings		Total	
	- - - - - - - - -	-	Stems per acres	(percent)	- - - - - - - - -			
Oaks								
Scarlet	364	(28)	369	(13)	274	(31)	1,007	(20)
Black	117	(9)	183	(7)	74	(8)	374	(8)
Southern Red	35	(3)	97	(4)	71	(8)	203	(4)
Post	32	(2)	56	(2)	13	(1)	100	(2)
White	13	(1)	25	(1)	26	(3)	64	(1)
Hickories								
Pignut	51	(4)	65	(2)	18	(2)	135	(3)
Mockernut	15	(1)	13	(*)	3	(*)	31	(*)
Other Potential Overstory Hardwoods								
Blackgum	99	(8)	572	(21)	106	(12)	776	(16)
Red Maple	357	(28)	174	(6)	117	(13)	647	(13)
Persimmon	17	(1)	29	(1)	4	(*)	50	(1)
Black Locust	14	(1)	31	(1)	3	(*)	47	(1)
Black Cherry	-	( )	1	(*)	-	( )	1	(*)
Understory Hardwoods (including shrubs)								
Sassafras	56	(4)	971	(35)	140	(16)	1,167	(24)
Dogwood	69	(5)	92	(3)	39	(4)	200	(4)
Sourwood	11	(1)	43	(2)	3	(*)	57	(1)
Serviceberry	10	(1)	22	(1)	6	(*)	37	(*)
Chinkapin	4	(*)	8	(*)	-	( )	13	(*)
Am. Holly	6	(*)	-	( )	-	( )	6	(*)
Am. Chestnut	-	( )	3	(*)	-	( )	3	(*)
Pines								
Virginia	24	(2)	-		1	(*)	25	(*)
White	3	(*)	-		-	( )	3	(*)
Totals	1,295	(100)	2,754	(100)	896	(100)	4,945	(100)

*When less than 1 values not recorded.

off both areas there were only 25 seedlings per acre in the regeneration, most of which were present as advanced regeneration. Pioneer species may become more important as seed drifts in from surrounding areas; however, early establishment is generally essential for these species to compete successfully.

Oak.--Scarlet Oak dominated the regeneration with 1,007 seedlings per acre (20 percent) followed by black oak with 374 seedlings per acre (8 percent), southern red oak with 203 seedlings per acre (4 percent), and post oak with 100 seedlings per acre (2 percent). White oak (Quercus alba L.) had only 64 seedlings per acre (1 percent). Oaks accounted for 35 percent of the regeneration.

They were represented in all three regeneration classes (old seedling, sprouts, and new seedling), but were most abundant in the sprout class and least frequent as new seedlings. Scarlet oak had 274 new seedlings per acre, the highest such count (16 percent) for the oaks.

Other Potential Overstory Hardwoods. This group accounted for 34 percent of the regeneration. Predominant species were blackgum (Nyssa sylvatica Marsh.) with 776 seedlings per acre (16 percent) and red maple (Acer rubrum L.) with 647 seedlings per acre (13 percent). Secondary associates were (in the order of decreasing importance) pignut hickory (Carya glabra Mill.), persimmon (Diospyrous virginiana L.), mockernut hickory (Carya tomentosa Nutt.), and black locust (Robinia pseudoacacia L.).

Black cherry (*Prunus serotina* Ehrh.) was rare, averaging only one seedling per acre. These secondary species accounted for only 5 percent of the regeneration.

The predominate regeneration type was sprouts; new seedlings were infrequent for all species. While blackgum and red maple were well represented in all seedling classes, red maple occurred most frequently as old seedlings and blackgum as sprouts. Among the secondary species black cherry occurred only as sprouts while the others were present in low numbers in all regeneration classes.

Understory Hardwoods (including shrubs). This group comprised 30 percent of the regeneration. Sassafras (*Sassafras albidum* (Nutt.) Nees) was dominant with 1,167 seedlings per acre (24 percent); secondary species included dogwood (*Cornus florida* L.)(4 percent), sourwood (*Oxydendrum arboreum* (L.) DC.) (1 percent) and serviceberry (*Amelanchier laevis* Wieg.), chinkapin, American holly (*Ilex opaca* Ait.) and American chestnut combined for the remaining 1 percent.

Sprouts were the common regeneration type for all species except American holly which occurred only as old seedlings. New seedlings were infrequent for all species. While sassafras regeneration was largely from sprouts (Table 1), most came from small diameter stems (Figure 1).

Pine. Virginia pine accounted for 0.4 percent of the new regeneration (25 seedlings per acre) and white pine (*Pinus strobus* L.) accounted for 0.1 percent (3 seedlings per acre). Most were old seedlings; new seedlings for both species averaged only one per acre. Almost all old seedlings had poor form due to deer browsing.

Sprouting Characteristics

Although a significant difference in composition between treatments was not found, differences in the number of sprouts were apparent. Since most of the sprouting was from smaller stems there was less sprouting on the diameter limit clearcuts as most small stems were left standing.

Species and diameter (or age) were primary determinants of the sprouting characteristics of cut trees. Small sapling-sized trees were the most prolific sprouters with almost all cut trees up to 5 inches dbh producing sprouts; however, a high proportion of these small diameter trees were shrubs. The diameter (breast height) below which species generally sprout when cut is shown in Figure 1. Sprouting vigor declines rapidly with increasing diameter (and age). The stage of most prolific sprouting ordinarily ends before the trees become effective seed producers.

Stump and basal sprouts (root collar area) were most vigorous suggesting that stumps should be cut as low as possible for well-formed coppice regeneration. Trees cut during the dormant period sprouted more vigorously than those cut during late spring and summer. This may be due to carbohydrate reserves in the roots that are at a minimum in the spring immediately after the formation of the new leaves and shoots, build up over the summer, and are highest during the winter.

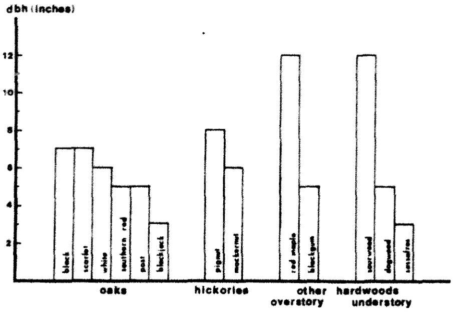

Figure 1. Diameter (bh) below which over 70 percent of the cut stems sprouted.

Uncut Trees

The two clearcutting methods resulted in a wide difference in the residual stands. In the diameter limit clearcut there were 197 residual trees per acre over 6 feet high, 80 of which were damaged in the cutting operation.

The small, open crowns of residual trees had not responded to release after one year and did not compete seriously with the developing stand. However, as their crowns fill out and larger root systems develop, they will compete more intensely with regeneration while that on the complete clearcut will be free to continue rapid development.

These residual trees do not have the potential for developing into a quality timber stand as many were damaged during the cutting operation and most were not desirable timber species. However, they are now dominants in the developing stand. While some will provide den cover and mast they will have a negative value for deer production.

Sassafras, dogwood, and sourwood accounted for the majority of the leave-trees that were not damaged. These are understory species and will decline in importance as potential overstory hardwoods overtop them.

Browsing

Leopold (1950) reported that severe browsing pressure is exerted during the critical winter months when the food supply is low. Continuous activity in the study areas (harvesting, exclosure construction, and follow-up treatment applications) during this period probably discouraged deer from browsing in the study area. While deer browsing was evident, deer exclosures were completed so late in the growing season that statistical testing of its impact was considered inappropriate.

Logging Slash

Zones of heavy accumulation of logging slash were created where trees were felled away from haul roads and skid trails. Joranson and Kuenzel (1940) reported that slash disposal is not a problem in the coppice method because the sprouts will come up through fairly dense cover and any reduction in the number of sprouts causes the growth to be concentrated on fewer stems. This suggests that site preparation is not required for coppice regeneration, as sprouts can come through logging slash and sprouting is not influenced by the condition of the forest floor.

Although a large percentage of the advanced regeneration in the diameter limit cut was damaged, buried, or crushed by slash, thin loose layers of slash may be of real benefit to young seedlings by protecting them from extreme temperatures, desiccation, and browsing animals. Grisez (1960) surveyed reproduction in logging slash 5 years after a heavy cutting in a black cherry-beech-maple stand. He found substantially larger numbers of preferred species in slash piles than in the intervening openings. In areas where deer browsing limits reproduction, hardwood slash may serve as a deterrent to browsing.

IN CONCLUSION

The findings of this study reflect stand characteristics one year after cutting. Periodic reinventory will be necessary to determine the effects of these cultural techniques over time and provide the validation needed to fine-tune the Phase I simulation model.

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DESIGNING FOREST OPENINGS FOR THE GROUP SELECTION METHOD[1]

Burnell C. Fischer[2]

Abstract.--SHADOS, a computer model for calculation of light received by small openings, was used to compare opening sizes commonly recommended for group selection. Square openings 0.5 to 4.0 tree heights receive 5% and 86% of full sunlight. North slopes and elongated openings of the same area received reduced light levels. Foresters practicing selection silviculture need to better understand opening size and shape relationships.

INTRODUCTION

Forest openings whether man-made or natural contain certain unique microclimates which are distinctly different from those found either under a continuous forest canopy or in large clearcuts. Because of the trend towards reducing the size of clearcuts to "patch clearcuts" and the increased use of the group selection reproduction method in hardwood silviculture, particularly on nonindustrial, private woodlands, there is a need to better understand how to design forest openings so that closer control can be obtained in management situations.

Even-aged (-sized) Silviculture

A silviculture system is the process whereby forest stands are tended, harvested, and replaced, resulting in a stand of distinctive form. A reproduction method is the procedure that results in the development of a new stand (Smith 1962). In uneven-aged silviculture, there is one system - selection. The two recognized reproduction methods of selection silviculture are single tree and group selection. In both of these methods, the stand is manipulated for a continuous high-forest cover, recurring regeneration of desired species, and the orderly growth and development of trees through a range of age or size classes to provide a sustained yield of forest products. Managed, uneven-aged (-sized) stands are characterized by trees of many sizes intermingled singly or in groups. Mature trees are harvested singly or in small groups, and the process of regenerating desirable species occurs either continuously or at each harvest. Harvests usually include thinnings and cultural treatments to promote growth and to maintain or enhance stand structure (Gibbs 1978).

The range of regeneration cutting methods in use today differ from one another primarily in their effect on light exposure. Both single tree and group selection harvesting create gaps or openings in the overstory canopy which allow some additional sunlight to reach the understory and/or the forest floor. Clearcutting permits maximal levels of sunlight to reach the ground.

Several silvicultural guides, although stressing the desirability of even-aged silviculture, do provide limited space for describing how ownership objectives may require some type of partial cutting or selection silviculture (Roach and Gingrich 1968; Leak, et.al. 1969). Generally, the practitioner is cautioned not to attempt single tree selection but to cut openings from a fraction of an acre to 2 acres in size. These opening sizes appear to be the best compromise between the "desire" for selection silviculture and the growth conditions required to have at least a portion of the regeneration composition be intolerant and mid-tolerant species.

Computer Analysis of Opening Light Dynamics

A series of studies at Purdue University has been undertaken to evaluate and produce practical computer models of light energy distribution within small forest openings (Fischer and Merritt 1978). A computer model for calculation of light

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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received by small forest openings, entitled SHADOS, was developed (Fischer 1974; Fischer and Merritt 1978). The model predicts the sun-shadow pattern on the floor of forest openings of any size, shape, aspect, and slope and for any latitude and selected time and day. Heights of trees surrounding the opening must also be specified. The computer model can also calculate the direct, diffuse, and total light energy received at any point on an opening floor for instantaneous or integrated time periods. In addition, an option of on-line graphing of sun-shadow patterns is available to the user.

Direct radiation is calculated by determining whether a given point on the opening floor is in the shade or sun for each sample time. When a point is found to be in the sun, the instantaneous direct beam solar radiation for that particular time is calculated and assumed for the selected time interval. A summation of direct energy is then derived for the total time period of interest.

Using SHADOS, I simulated direct solar radiation for clear, sunny days (atmospheric transmission coefficient 0.60), monthly during the growing season (April 12 - August 30) for square openings for a latitude of 40°14'00". Table 1 shows the effect of aspect, slope and opening size on the percent of direct solar radiation received by the floor of square forest openings. All percentages in this paper are based upon averages for the entire opening floor and are expressed as a percent of direct solar radiation received by an open horizontal surface of equivalent area.

For simplicity, only two aspects, 0° (north) and 180° (south), are depicted. Slopes of 0, 15 and 30 degrees give a total of five aspect/slope combinations for each of four opening sizes ranging from 0.5 to 4 tree heights (H).

Table 1 demonstrates the large increases in direct solar radiation received as opening size increases from 0.5 to 4 tree heights. Also, the effect of a north aspect on the percent of direct solar radiation received by openings is apparent with all size openings.

It is important to realize that the opening sizes shown in Table 1 are in the range commonly recommended for group selection. I have shown opening sizes in terms of tree heights because the relationship in regular openings of opening-diameter to perimeter tree-height determines the light energy distribution on the opening floor. The area for the four openings illustrated in Table 1 would be 0.03, 0.11, 0.45 and 1.80 acres for a perimeter tree height of 70 feet. For a perimeter tree height of 90 feet, corresponding areas would be 0.05, 0.19, 0.74 and 2.98 acres.

Table 1.--Effect of aspect, slope and opening size on the percent of direct solar radiation received by the floor of square openings.

Aspect/Slope (deg./deg.)	Opening size in tree heights 0.5	1.0	2.0	4.0
		percent		
0/30	1	15	34	57
0/15	4	19	47	74
0/0	5	24	56	86
180/15	5	30	66	89
180/30	12	37	66	87

It is interesting that Daniel, et.al. (1979) recommend a maximum size of one to two tree heights for group openings so as not to lose the site protection by the surrounding trees. On the other hand Marquis (1965) has discussed controlling light with small clearcuttings not to exceed 1 acre in size. Merritt's (1979) conclusion that openings must have at least a 50% fully open, unprotected microclimate to qualify as a clearcut appears a more reasonable silvicultural definition. This corresponds to openings of at least 4-6H (Fischer 1979).

To evaluate effect of shape and orientation on opening light dynamics I simulated direct solar radiation as in Table 1 for openings of 1 and 2 tree heights (aspect/slope, 0°/0°). For each of these opening sizes I maintained the same opening floor area by halving the dimensions in one direction and doubling the dimensions in the other. Then, I repeated the process a second time. This results in a square 1H opening first being transformed to a 1/2H by 2H opening and then to a 1/4H by 4H opening. These openings were oriented with the long axis east-west and then north-south. The percent of direct solar radiation received by the floor of each opening shape and orientation was calculated. These results are shown in Table 2.

The comparative decrease in light energy received at the opening floor particularly in the openings that were 16:1, is quite large. These results demonstrate that square or circular openings maximize direct light levels and elongated openings of the same size and area receive less direct light.

Of course, both orientation and width affect the amount and pattern of sunlight. Narrow openings (strips) that are oriented east-west receive more direct sunlight early in the morning and late in the afternoon but are relatively protected (shaded) during mid day. North-south openings receive most direct light around noon when solar intensity is greatest and are more shaded earlier and later in the day. This explains the higher value in the narrow 1/4 by 4H north-south oriented opening.

Table 2.--Effect of shape and orientation on the percent of direct solar radiation received by the floor of 1 and 2 tree height forest openings.

Opening Dimensions in Tree Heights	Orientation of Long Axis East-West	North-South
	Percent	
0.25 x 4.0	5.1	12.2
0.5 x 2.0	18.6	17.9
1.0 x 1.0	24.3	
0.5 x 8.0	31.3	22.7
1.0 x 4.0	57.0	34.3
2.0 x 2.0	55.6	

Silvicultural Considerations

The wide range in percent direct solar radiation for 0.5H to 4H openings shown in Table 1, and the lower light levels in north facing and elongated openings (Table 2) demonstrate the great variation in opening microclimates within narrow size limits. Thus, the field forester, who is practicing group selection silviculture, must be very precise in choosing and marking groups to achieve his silvicultural objectives.

In the upland Central Hardwood stands of Indiana, as well as in all eastern hardwood forests, high light levels are prerequisite for the growth of the more valuable intolerant species, and apparently necessary for the perpetuation and release of advanced oak regeneration (Fischer 1979). At least 90% of the commercial forest land in the Central Region is in nonindustrial private ownership, usually in small acreages probably averaging less than 40 acres (Merritt 1979). These woodland owners generally "demand" uneven-aged (-sized) silviculture and foresters attempt to provide it through group selection so that the more desirable mid- and intolerants are regenerated. How successful are these foresters?

In a recently completed study (Callahan and Fischer 1980) of 23 selectively harvested woodlands an assessment of the overstory canopy at 264 inventory plot locations in the 23 woodlands clearly showed that openings in the canopy were characteristically small (Table 3). At nearly 90 percent of the plot locations, the canopy openings were less than one tree height in width (about 60-70 feet). In only five percent of the cases were the openings sufficiently large (two to three tree heights in width) to be significant in the stimulation of advanced oak regeneration and other intolerant species. Characteristically, these woodlands, as well as many in the Central Region are regenerating primarily to lower-valued tolerants and undesirable species. Clearly, foresters practicing selection silviculture need a better understanding of opening size and shape as related to needs of tree regeneration for sunlight.

Table 3.--Size of openings in the overstory canopy above 264 inventory plot locations in 23 Indiana woodlands following selection harvesting.

Opening Size[1] in tree heights	No. of Plots frequency	Frequency percent
0	188	71.2
0.5	42	15.9
1.0	19	7.2
1.5	2	.8
2.0	8	3.0
2.5	0	0
3.0	5	1.9
Totals	264	100

Conclusions

It is apparent that high light levels are necessary for the growth of both new seedlings and advanced hardwood regeneration and that these light conditions cannot be achieved by the single tree selection method. Group selection, however, offers the possibility of creating forest openings of sufficient size to attain these high light levels.

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[1] Opening size is the diameter of the tree canopy opening in which the 1/10 acre plot was located. Diameter was estimated in dominant tree height units to the nearest 0.5 tree height.

The light energy received on the floor of a forest opening of any size, shape, aspect and slope can be predicted by a computer model. By incorporating stand characteristics and the desired regeneration layer response with the results of the model, forest openings can be precisely designed to achieve many silvicultural objectives.

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A COMPARISON OF REPRODUCTION AND GROWTH AND YIELD AFTER 36 YEARS FROM FOUR REPRODUCTION CUTTING METHODS IN LOBLOLLY-SHORTLEAF PINE STANDS [1]

James B. Baker and Paul A. Murphy [2]

Abstract.--Four reproduction cutting methods employed on a good site in second-growth loblolly-shortleaf pine in south Arkansas provided adequate pine regeneration to establish or maintain well stocked stands. During the 36-year study period, seed-tree and diameter-limit cutting methods produced significantly more cubic-foot volume than selection and clearcutting, while clearcutting resulted in significantly less board-foot (Doyle) volume.

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[2] Authors are Principal Silviculturist and Principal Mensurationist, Southern Forest Experiment Station, U. S. Forest Service, Monticello, Arkansas.

SILVICULTURAL CONSIDERATIONS IN DEVELOPING INTEGRATED SOUTHERN PINE BEETLE MANAGEMENT PROCEDURES[1/]

Roger P. Belanger[2/]

Abstract.--Silvicultural principles and practices are integrated into the research and development components of a pest management procedure designed to prevent or reduce losses from the southern pine beetle. Research and user needs are identified related to the planning, selection, and implementation of forest protection strategies.

INTRODUCTION

The development, integration, and implementation of strategies and practices to prevent or reduce serious losses from insect and disease pests are new and complex undertakings in southern forestry. Although the definition of integrated pest management (IPM) may differ by organization and individual, the concept generally involves the selection and use of protection activities based on predicted economic, ecological, and sociological consequences (Bottrell 1979). A model structure for forest pest management (fig. 1) shows the research and operations action flow needed to develop an integrated protection plan. This approach has been the framework for the major activities within the Expanded Southern Pine Beetle Research and Applications Program (ESPBRAP) started in 1975. The basic components of IPM--pest population dynamics, forest stand dynamics, treatments, and impact--are closely related to one another. Primary disciplines involved in the developmental process are entomology, pathology, silviculture, mensuration, economics, and management. Previous knowledge has been combined with new technology to provide the data inputs required to structure and sequence the system. This paper describes how silvicultural principles and practices can be incorporated into the research and operations components of IPM procedures designed to prevent or reduce losses from the southern pine beetle (SPB - Dendroctonus frontalis Zimmermann).

The Stand Component

The stand is the basic link between pest population dynamics, impact assessment, and treatment (Waters and Stark 1980). It is also the basic unit of silviculture. An extensive coordinated southwide ESPBRAP effort identified stand conditions associated with SPB attacks and developed systems for ranking the susceptibility of stands to beetle attack. Site conditions, tree species and size classes associated with SPB attacks differ somewhat between the Coastal Plain, the Piedmont, and the Southern Appalachian Mountains (table 1). However, slow radial growth and dense stocking are common characteristics of high-hazard stands.

Hazard ratings indicate where beetle outbreaks are most likely to occur and, if they do, where beetle activity and losses are likely to be greatest. Several rating systems have been developed that provide an evaluation of potential risk. Testing and implementing the ranking systems have been limited to stand, site, and insect conditions associated with selected areas in the geographic subregions.

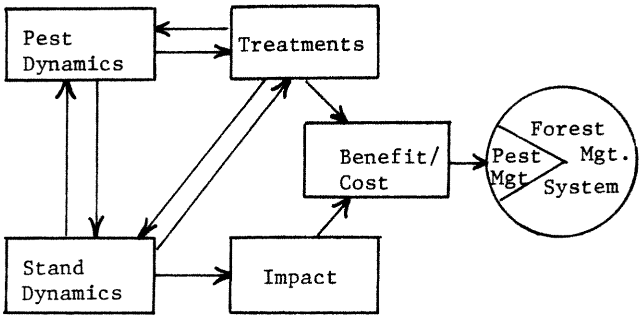

Figure 1.--The structure and sequence of a model integrated pest management system (from Waters and Cowling 1976).

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Table 1.--Characteristics of Natural Stands Susceptible to SPB Attack

Southern Coastal Plain	Piedmont	Southern Appalachians
Densely stocked stands	Well-stocked stands	Densely stocked stands
Large proportion of sawtimber	Small sawtimber	Large proportion of overmature sawtimber
Declining radial growth	Slow radial growth during last 10 years	Slow radial growth
Poorly drained soils and low-lying areas	High percentage of clay in surface and subsurface soils	Dry, south-facing slopes
High percentage of shortleaf and/or loblolly pine in the stand	High percentage of shortleaf pine in the stand	High percentage of shortleaf and/or pitch pine in the stand

The Southern Coastal Plain.--Natural stands susceptible to beetle attack in the Gulf Coastal Plain are characterized by high stand densities, a large proportion of pine sawtimber and declining radial growth. Outbreaks occur more frequently in stands located on poorly drained, moist sites than on dry and droughty soils. Rating systems have been developed in the Coastal Plain for East Texas (Hicks et al. 1980; Mason 1981), the Kisatchie National Forest in Louisiana (Lorio 1978; Lorio and Sommers 1981), corporate timberlands in Texas, Louisiana, and Mississippi (Kushmaul et al. 1979), and forests in South Arkansas (Ku et al. 1980).

The Southern Appalachians.--Studies in the mountains of Georgia, North Carolina, South Carolina, and Tennessee showed that stands most subject to SPB attack were densely stocked, slow growing, and had a large proportion of overmature pine sawtimber (Belanger et al. 1979; Belanger and Hatchell 1980). Shortleaf pine (*Pinus echinata* Mill.) and pitch pine (*P. rigida* Mill.) were more susceptible to beetle attack than Virginia pine (*P. virginiana* Mill.) and loblolly pine (*P. taeda* L.). The majority of infestations were recorded on south-facing slopes. However, this aspect is where most of the pines occur in the Southern Appalachians.

The Piedmont.--Natural stands susceptible to SPB attack in the Piedmont are well-stocked pine stands with a large percentage of the host component in shortleaf pine, slow radial growth during the last 10 years, and a high clay content in surface and subsurface soils (Belanger et al. 1977; Maki et al. 1978; unpublished). Two systems have been developed for ranking the susceptibility of natural stands to SPB attack in the upper Piedmont of Georgia. The first is a predictive equation that includes variables easily measured or often contained in existing inventories (Belanger et al. 1981); the second is a system designed for use in the field by service foresters (Belanger and Price 1979).

In summary, unhealthy stands are highly susceptible to attack by the SPB. This familiar and basic principle applies regardless of region or pine type.

The Treatment Component

Several silvicultural and direct control options are available that will prevent or reduce losses from the SPB (fig. 2). Silvicultural practices can lower the susceptibility of stands to beetle attack by increasing stand vigor. Direct control practices are used to prevent additional losses in stands that have been attacked by the beetle.

Preventative Silviculture

Proper silvicultural treatment of forest stands is an essential element in developing strategies to achieve long-term success in reducing losses from the SPB. Intermediate cuttings and regeneration methods provide the means to produce environmental and biological conditions unfavorable to the attack, spread, and population growth of this forest pest. No "standard" recommendation will apply to all situations. Each forest condition and locality presents different management problems; each might require a different combination of methods to increase resistance to SPB attack. General

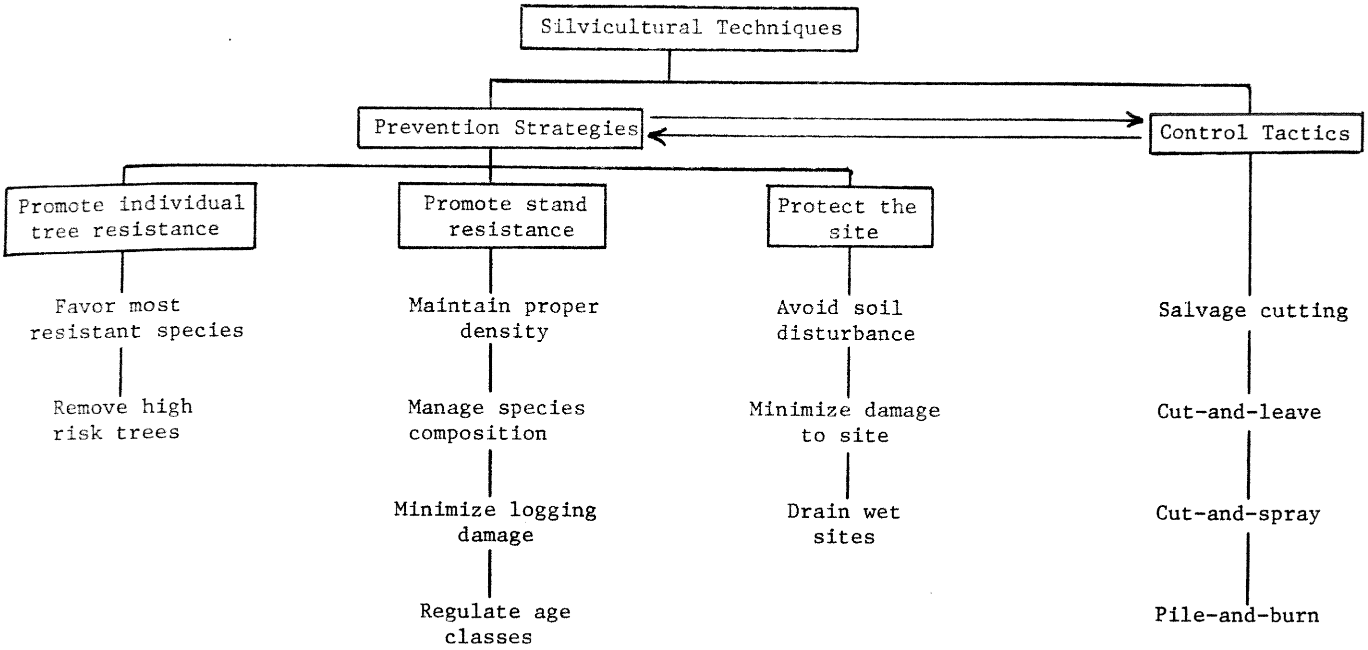

Figure 2.--Silvicultural guidelines to reduce losses from the southern pine beetle.

guidelines have been developed based on past and ESPBRAP supported research (Bennett 1968, 1971; Hedden 1978; Hicks *et al*. 1979; Belanger 1980; Belanger and Malac 1980) to reduce the potential for losses. These include:

- Favor tree species that are most resistant to SPB attack (table 2) and best suited to the site (Coyne and Lott 1976; Hodges *et al*. 1977, 1979; Belanger *et al*. 1979, 1981; Ku *et al*. 1980).
- Salvage trees damaged by lightning, wind, ice, and other destructive agents. Pines struck by lightning offer a favorable environment for the SPB and several species of *Ips* beetles. (Hodges and Pickard 1971). Stands with trees damaged by wind, ice, and hail are more susceptible than undisturbed stands.
- Thin to reduce competition, remove slow growing trees which are subject to SPB

Table 2.--The Susceptibility of Pines to SPB Attack for Major Geographic Regions of the South

Levels of susceptibility	Geographic Region Coastal Plain	Piedmont	Southern Appalachian
Most resistant	Slash Longleaf	Virginia Loblolly	Virginia Eastern white
Most susceptible	Shortleaf Loblolly	Shortleaf	Shortleaf Pitch

attack (Haines et al. 1976; Ku et al. 1976), and stimulate vigor in young stands. Degree of thinning is determined by the intensity of management, the kind of product desired, available markets, and natural conditions specific to each location. Basal areas of 80 to 100 ft^2/acre are recommended to reduce the hazard ratings of stands (Hicks et al. 1979; Belanger 1980; Belanger and Malac 1980).

* Manage a mixture of pine and hardwood species. The SPB prefers pure pine stands. A mixture of pine and hardwood species reduces the potential for spot incidence and growth (Belanger et al. 1979; Hedden and Billings 1979).

* Use harvesting systems that minimize logging damage. Logging activity has a tendency to increase SPB attack (Porterfield and Rowell 1980). Mechanical injury to above- and below-ground portion of residual trees also provides attack courts for the black turpentine beetle (BTB- Dendroctonus terebrans Olivier) and Ips spp.

* Regenerate mature and overmature stands. Susceptibility of stands to SPB attack increases with age throughout most of the South (Lorio 1978; Belanger et al. 1979; Coster and Searcy 1980).

* Protect the site as much as possible. High-hazard sites in the Piedmont are characterized by a high percentage of clays in the surface and subsurface soil horizons (Belanger et al. 1981). Infestations in the Coastal Plain occur more frequently on wet and water logged sites than on well-drained sites (Lorio and Hodges 1971; Belanger et al. 1977; Hicks et al. 1979). Abuse of these delicate sites will only increase SPB problems in the future.

Control Practices

Infested trees can be salvaged to utilize merchantable material or simply felled into openings and exposed to maximum sunlight. Brood mortality can be increased by high inner-bark temperatures (Hodges and Thatcher 1976). Sanitation cuttings remove damaged, infested, and high-risk trees to prevent the spread and proliferation of the SPB. If salvage removal or cut-and-leave are used, and fresh attacks are present, a buffer strip of uninfested pines should be cut around the active head of a spreading spot to interrupt the advance of the beetle (Billings and Pace 1979). As a rule of thumb, width of the buffer strip should be roughly equal to average tree height in the spot (Billings 1980).

The forest manager may elect to treat a stand to modify beetle activity, or he may risk beetle infestations, rely on intensive surveillance for detection, assess potential damage to the stand, and assign (or not assign) treatments accordingly. Decisions are made on a case-by-case basis. Size of the stand, value of the stand, existing markets, and management objectives all enter into evaluating alternatives. Information from the insect dynamics and impact components should also be considered when deciding what SPB strategies will best benefit resource objectives.

Insect Dynamics

SPB populations typically rise and fall over time. Unfortunately, these cycles are irregular and unpredictable. The silviculturist and forest manager are at a disadvantage when beetle populations are high. Any preference by the SPB for particular stand conditions are masked by the indiscriminant development and spread of infestations associated with epidemic beetle populations (Belanger et al. 1981; Mason 1981). Infestations can develop and persist even in relatively sparse stands if levels of beetle activity and rates of attack are high (Hedden and Billings 1979). Direct control practices during these conditions are emphasized out of necessity.

Silvicultural activities related to forest pest management are generally neglected during periods of low beetle activity. Yet, this is the time when the planning and application of prevention strategies should be greatest. High-hazard stands can be identified and treated to reduce their susceptibility to beetle attack. At this time mill quotas include very little salvage wood and operators are available to conduct intermediate cuttings. Also, endemic "reservoirs" of SPB-infested trees and high-risk trees are removed and more growing space is provided for residual trees. The probability of spot initiation and spread is lowest when insect populations are down. Low-hazard stands can be tended to maintain vigor and rapid growth.

Historical records of SPB activity can be useful to silviculturists and forest managers concerned with protecting forest resources. For example, beetle incidence, spot proliferation, and spot growth during the last three major SPB outbreaks in the Piedmont of Georgia were consistently more severe in some counties than in others. Obviously, prevention and suppression activities should be concentrated in the problem counties. From a research standpoint, we need to determine what the differences are (stand ? site ? climate ?) between areas that historically have been hard-hit and areas that have few beetle problems.

Beetle behavior varies during different seasons of the year. Studies in East Texas showed that beetle populations disperse and initiate multiple-tree infestations primarily during the spring; spot growth replaces spot proliferation as the primary mode of beetle colonization during the summer (Hedden and Billings 1979). Treatment of high-hazard stands can influence the spread of the SPB during most years. Silvicultural practices that promote stand vigor will decrease the probability of beetle attack. Sparse pine stocking will restrict the number of trees being killed once the spot has been initiated. Density of the pine component can be regulated by manipulating stocking levels, making intermediate cuttings, and favoring pine-hardwood stands.

Impact

The responsibility of the silviculturist is to produce and maintain a forest that best fulfills the objectives of the owner (Smith 1962). Traditionally, the primary concern of the silviculturist has been to maximize the production of wood crops. Today the silviculturist is also being asked to answer questions concerning the impact of regeneration methods, intermediate cuttings, and protection strategies on the environment, economy, and people (Stark 1979). The silviculturist is generally not trained to answer these questions and must turn to specialists in other disciplines for help. This, in large part, is what integration is about. Following are examples of how silvicultural practices can impact multiple resource values.

Environmental Impact

Thinning is recommended to reduce stand density and increase stand vigor. The forester must be aware, however, that intermediate cuttings on certain sites can promote infection and spread of annosum root rot (Heterobasidion annosum (Fr.) Bref). Studies have shown a close association between this disease and SPB attack (Alexander et al. 1980). Precautions should be taken to reduce the danger of annosum infection. Intermediate cuttings should be scheduled during summer when fewer H. annosum spores are produced and high temperatures may kill those that are produced. Treating stumps with borax or the antagonistic fungus Peniophora gigantia minimizes spread. Prescribed burning before and after thinning also reduces severity of annosum root rot in the South (Froelich et al. 1978). Stand-site studies have shown no relationship between burning and SPB attack.

Economic Impact

Some forest managers consider intermediate cuttings to prevent SPB attack a "luxury." This may be the case if stands are being managed using short rotations and the primary objective is pulpwood. It may not be the case if you are managing for multiple products under longer rotations.

High-hazard stands often contain quality, sawtimber-size trees. Losses from SPB attack and rapid spread in these high value stands can be enormous. Benefits from prevention and control measures may exceed the costs of treatments if these stands are needed to meet management objectives. Stand growth models for plantations and naturally seeded stands allow simulation of management practices on tree growth (Daniels and Burkhart 1975). The forest manager can use these models to determine which course of action may be best suited to individual stands and ownership objectives.

Sociological Impact

Damage to stands by the SPB can influence the value judgment of people. Studies conducted on the Blue Ridge Parkway in Virginia showed that viewers responded adversely to areas of beetle-killed trees (Buyhoff and Leuschner 1978). SPB damages were also estimated for intensively used recreation sites in East Texas (Leuschner and Young 1978). Onsite damages ranged from $3,500 to $1,204,000 depending on the recreation site, the severity of attack, and whether travel time costs were included. The investigators concluded the potential damage reduction on recreation sites combined with the small area requiring treatment may well justify intensive prevention and/or suppression activities.

IMPLEMENTATION: BARRIERS AND PROGRESS

Some of the technology needed to develop strategies and practices that will reduce losses from the SPB is in hand and being transferred to users. Yet, most resource managers have been reluctant to incorporate this knowledge into their planning, decision making, and operations. What are the silvicultural needs that contribute to this impasse? First and foremost, the manager is looking for convincing evidence that prevention strategies and control practices are effective and efficient in reducing SPB losses. The net effect of recommended practices must produce tangible benefits that contribute to the objectives of management.

There is the question as to where and under what conditions hazard rating systems can be applied. For example, can stand hazard rating models developed in the Piedmont of Georgia during endemic beetle conditions be used to accurately rate the susceptibility of stands in Georgia (or elsewhere) when populations are high? Do hazard rating systems developed for natural stands apply to plantations? Will stands treated to prevent or reduce attacks from the SPB increase or decrease damage from Ips spp. black turpentine beetles, or tree-killing diseases?

Some of the rating systems require variable inputs that are difficult and expensive to obtain. Can these systems be simplified and still provide meaningful information for management decisions? What level of accuracy will users be willing to accept?

Managers have equally long lists of questions related to the other subject matter represented in the components of the proposed SPB system. Perhaps the integration--as envisioned--is too cumbersome, difficult, and rigid to be readily incorporated into resource management systems. The Integrated Pest Management RD&A Program on Bark Beetles of Southern Pines[3] will address some of these questions during the next five years. Meanwhile, managers that are experiencing or wish to avoid severe losses from the SPB may want to examine and include some of what we do know about the beetle in their management programs. Methods for making better control decisions can be strengthened as additional information related to "integrated forest protection" becomes available.

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SILVICULTURAL CONSIDERATIONS FOR MANAGEMENT OF SLASH PINE IN LOWER COASTAL PLAIN WETLANDS[1/]

C. A. Hollis, R. F. Fisher and W. L. Beers, Jr.[2/]

Abstract.--Portions of the coastal lowland provinces of the Lower Coastal Plains are potentially productive and manageable sites if proper consideration is given to the biological needs of slash pine and to the constraints imposed by the site itself and BMP guidelines. Most of these sites require some surface water management for access, seedling survival and tree growth. Our studies show that most water quality problems are related to suspended particulates generated by activities on or adjacent to roads. However, such impacts are of short duration and virtually all evidence of site disturbance disappears within the first year. Thus, opportunities exist for scheduling of silvicultural activities to minimize water quality impact.

Most of these sites are deficient in phosphorus and require fertilization to insure adequate stocking and early height growth. Current evidence indicates that choice of fertilization and timing of applications may substantially reduce water quality impact and improve effectiveness of this operation.

Substantial limitations to tree growth appear to be related to high water table restrictions on root development. Although, partly confounded by nutrient immobilization in the high organic matter fraction of the soil and losses to run off, preliminary evidence suggests that survival, root volume, stem diameter and height growth of young seedlings is proportional to depth of the oxygenated zone of the rhizosphere. Also, opportunities for improving survival and effectiveness of fertilization with mycorrhizally inoculated planting stock appear evident.

[1/] Paper presented at the Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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SILVICULTURAL OPTIONS QUANTIFIED: (1-1) SILVICULTURE

Frank W. Woods[2]

A method for quantifying silvicultural options, called (1-1) silviculture, is presented. The notation for expressing (1-1) harvest cuts is revealed. Inclusion of intermediate cuts, their intensities, and grouping effects are shown to be the next necessary development.

INTRODUCTION

Forestry in the United States, as well as throughout the entire world, has been strongly influenced by methods and practices developed in Germany during the 19th century. So strong have been the traditions, that there have been practically no efforts either to examine their basic underlying philosophy or to evaluate their fitness for contemporary needs. This is a tribute to the validity and utility of the silvicultural systems themselves, and a rebuke to those who have accepted the status quo as, "good enough for me." The fact is that the systems have been conceived independently to meet needs as they arose. As a consequence, there is no progressive flow from one to the other and it is not possible to use quantitative differentiation as the basis for selecting one or the other. Such decisions have been, and are today, subjective rather than objective. In the past we have justified this stance by saying, "After all, silviculture is part art and only part science."

There has been only one flurry of activity in which anything remotely resembling the approach proposed here has been investigated. Usher, an English worker, was active in the late sixties (1966, 1967, 1969) and Bosch (1971) shortly thereafter. Neither the most recent German silviculture text (Mayer 1977) or American (Smith 1962) indicate a need for a new trend. In an overview of probable silvicultural changes in the future by Smith (1972) and more recently by Florence (1978), there is still no indication that quantification of silvicultural options would, could, or should emerge.

This attitude cannot long continue. Decision-making is now constrained by so many variables and qualifications that in the future it will be possible to make rational silvicultural choices only with computer-based assistance. Forest managers have, for many years, used tools such as linear programming, capital budgeting, and marginal analysis. Harvest scheduling and multiple use tradeoffs can be readily resolved by use of these techniques. But once a decision is made to pursue and optimize a particular set of goals, the choice of silvicultural methods becomes highly subjective.

For the purposes at hand I have concerned myself only with the nomenclature of <u>harvest cuts</u> in a new approach to silvicultural management, called (1-1) silviculture. The intermediate cuts, and the techniques for arriving at the optimal solution for any desired set of needs will be considered in a future paper.

OBJECTIVES

The goals of the project reported here are to:

(1) develop a notation which will describe any segment from a continuum of possible harvest cuts;

(2) produce subscript which will describe intermediate and harvest cuts; and

(3) produce a subscript which will describe how trees should be grouped in a forest stand.

THE RATIONALE

The harvest cut is the prime determinant factor in (1-1) silviculture, and will be the only operation considered in this paper. It culminates the <u>total increment period</u> (TIP) and may be interrupted by <u>intermediate cuttings</u> with <u>cutting cycles</u> of whatever length best serves a particular need. In this respect it is not different from some of the systems already in use.

The concept of the rotation is not propagated in this system because it is largely a myth. For a single-aged, single-species stand, a rotation length of sorts can be based on a combination of economic and biological factors. But mitigating against even the most perfect of selection and even-aged forests are fire, insect attacks, road construction, air pollution, and other factors which require the early removal of immature trees, and leaving trees which must exceed maturity in order to sustain yield.

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[1] Paper presented at the Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-8, 1980.

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Even though the (1-1) system is a continuum, it has six easily recognizable phases. At one extreme is never-cut silviculture (Fig. 1). The hard-core silviculturist may argue as he has in the past, that without cutting there can be no silviculture. However, since the decision to cut or not-to-cut is a management option, never-cut is as valid as any other alternative. For the preservation of natural and wilderness area, unique kinds of habitats, and wild gene pools that might be destroyed or decimated by tree cutting, it may be the only tenable choice. The species composition of the system must be extremely shade-tolerant if reproduction is to be consistent over long periods of time.

The next category of silvicultural systems includes a continuum of selection-cuts characterized by the fact that stocking is never allowed to reach the zero (0) level. Figures 2, 3 and 4 illustrate selection cutting, with Figure 2 closely related to traditional high-forest selection. The age distribution of trees in Figure 4, and the time-sequence of basal area removal aproaches that which we would find under a shelterwood system. Since any forest stand managed under selection silviculture (1-1) is always stocked, the species which lend themselves to partial-cut necessarily must be at least moderately shade-tolerant.

Figure 5 represents N-A (never-cut and always-cut) silviculture, which results when a mature forest stand is clearcut and left to grow to maturity once again. Because commercial forests are seldom allowed to grow to maturity, it represents a theoretical rather than actual management alternative. Absentee ownership, with periodic clearcutting can produce this pattern.

Figure 6, 7 and 8 illustrate clearcut silviculture in which the stand is periodically clearcut, but never allowed to reach 100% of its growth potential. Figure 6 illustrates a phase similar to the sequence in which pulpwood is frequently produced. Maximum water yield (Figure 7) and wildlife browse and shelter (Figure 8) might be provided by other phases of clearcutting. Species used in this type of silviculture, usually will be intolerant of shade.

Figure 9 illustrates always-cut silviculture, in which all trees are cut at least once each year to maintain a treeless condition. Power line rights-of-way, roadside vistas, and rights-of-way along highways are examples. Here, again, is a silvicultural choice which can be dictated by special conditions and pressures, and which some forest managers might argue--is not true silviculture. Yet, the decisions regarding its use must be made using the same criteria used in which other options are chosen, which is the basis of silvicultural management.

Figure 10 and 11 illustrate S-C (selection-clearcut) silviculture, which combines the features of total and partial cutting. Stocking is never allowed either reach 100% or to drop to 0%. The age distribution of the traditional shelterwood system bears a resemblance to that of Figure 10.

To quantify these options is not difficult. Numerically, we have one number, always positive, which describes the lowest point which stocking is ever allowed to reach. A second number, always negative, describes the highest point that stocking is ever allowed to reach. To express any cutting option therefore requires the use of two numbers, hence the name of the system, (1-1) silviculture. Its value lies in its capacity to quantify the total range of cutting options in such a manner as to present a continuum of choices which are subject to objective decision making. A few examples will help to explain the notation.

In Figure 1, never-cut silviculture is shown to have a value of (0-1), a value which never changes because stocking is always 100%. The percent value, with which all phases are described are divided by 100 to produce numbers which are more manageable when placed in a matrix for "number crunching." Hence, all values will be between $^{+}1$ and $^{-}1$.

In Figure 2, the selection option depicted has a value of (.75 - 0), but it can range from (.01 - 0) to (.99 - 0), in the same manner that clearcut silviculture can vary from (0 - .01) to (0 - .99). N-A silviculture (Fig. 5) always has a value of (0-0), because it is a hybrid of never-cut and always-cut silviculture.

S-C silviculture is illustrated in Figures 10 and 11. For this option, stocking is never allowed to reach either 100 or 0 percent. Figure 10 illustrates (50-20) while Figure 11 illustrates (25-25) silviculture.

A steady state stand with less than full stocking can be expressed. Figure 12 provides an example of (.75 - .25) silviculture, which is only one of many possibilities.

Note that it is not possible to have a stand for which the maximum allowable is greater than the minimal allowable growth. Therefore, a (.75 - .30) or a (.50 - .55) stand is not possible.

There are other aspects of the system that need consideration. We must develop the notation for stand information, the "Y" values if you wish, which will express

(1) rotation length,
(2) the timing and intensity of intermediate cuts,
(3) grouping effects, and
(4) any other information about stand structure that is necessary for stand manipulation.

The notation must be derivable by calculation and not merely a qualitative symbol. It will be acceptable, initially, to develop a notation which can be applied to a single stand of trees; however, it must ultimately be developed to express forest conditions, responding to both biological and economic inputs.

The notation for the silvicultural option, which itself is a model, must not be confused with the multi-criterion decision-making model which shapes it.

Even though the system of silvicultural alternatives presented here is in the infancy of its development, it offers a new and unique opportunity for quantifying silvicultural alternatives.

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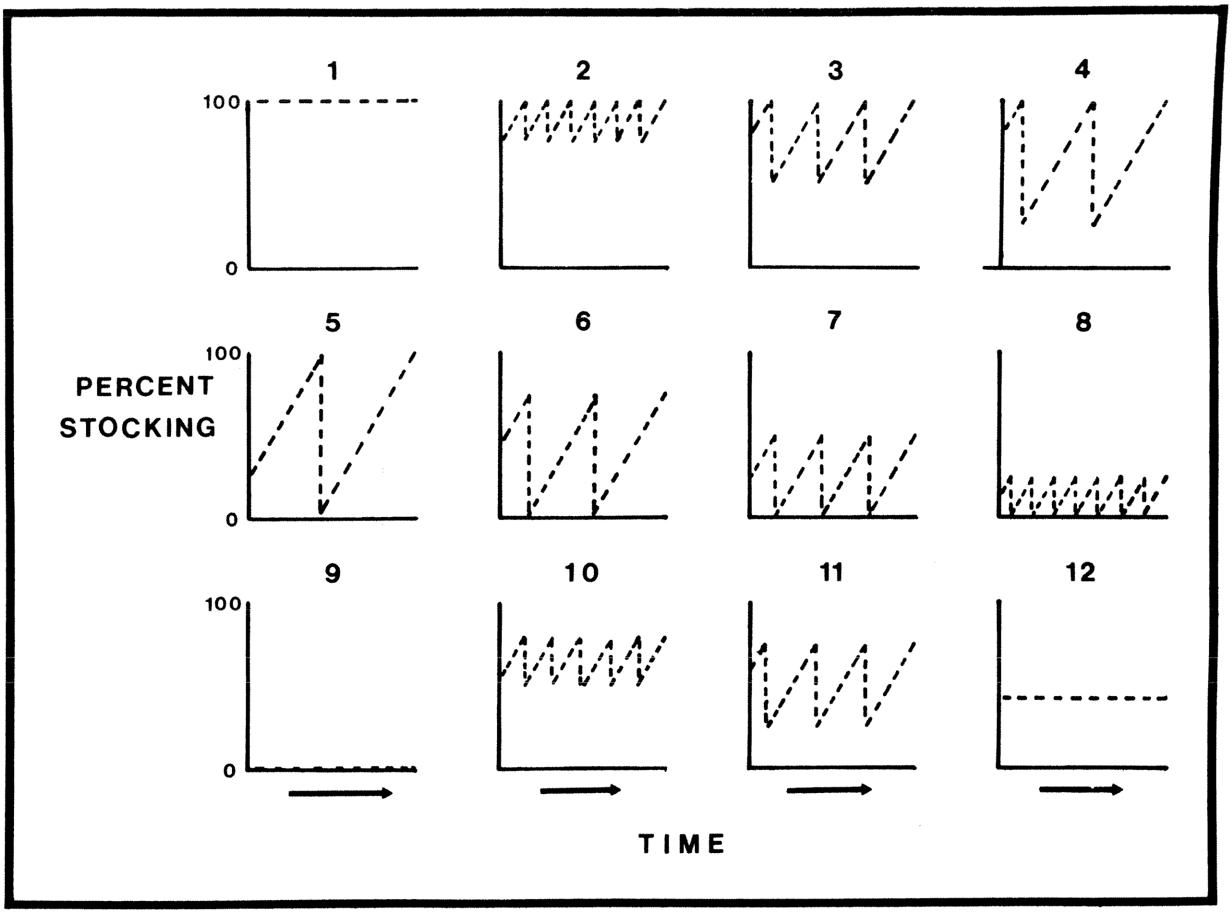

Figures 1-12. -- Silviculture (1-1) yields an infinite number of possibilities for harvest cuts. Each of the twelve possibilities illustrated have been discussed in the text.

MINIMUM STOCKING LEVELS REQUIRED FOR SUCCESSFUL MANAGEMENT OF UNEVEN-AGED LOBLOLLY-SHORTLEAF PINE STANDS [1]

B. F. McLemore [2]

Abstract.--Loblolly-shortleaf pine stands on medium and good sites in south Arkansas were cut to stocking levels of 10, 20, 30, 40, and 50 percent, based on a tree-area ratio stocking equation. Residual stems ranged from seedlings to 12 inches dbh and were distributed with a Q-factor of about 1.2. Future measurements will determine recovery rates and minimum stocking levels necessary for successful rehabilitation and management.

INTRODUCTION

In the South, 73 percent (140 million acres) of the commercial forest land is fragmented among more than 1 million private, nonindustrial owners. The average net annual growth of timber on these lands is about one-half the minimum potential of 76 cubic feet/acre/year. Yet these are the forests that must produce a major portion of the predicted twofold increase in demand on southern timberlands by the year 2000. Because need for improving the private landowners' timber production is so urgent, the National Forest Management Act of 1976 and RPA's Renewable Resources Program for 1977-2000 charged the Forest Service with developing alternatives to even-aged management and management systems suitable for private nonindustrial landowners.

Several studies have indicated that uneven-aged management may suit the nonindustrial landowner's objectives better than the intensive even-aged management practiced by most Federal, State, and industrial land managers. A major problem in placing private land under management is the poor condition, or low stocking levels, often found on this land.

Research on the Crossett Experimental Forest has demonstrated that forest properties having as little as 38 ft.^{2} basal area, or 2,000 bd.ft./acre (Doyle) sawlog volume, can be quickly rehabilitated. However, many private ownerships today have stands with stocking levels below 2,000 bd.ft./acre. The question arises, then, as to how poorly stocked a stand may be and subsequently recover after being placed under management. Two studies in south Arkansas were designed to answer this question.

METHODS

Measurement of Stocking

A prerequisite for these studies was development of a means for measuring stocking levels. Stocking, or density, may be expressed in absolute measures which express the density on an area basis. Relative density is based upon a standard. For these studies, density as defined by the tree-area ratio is used (Chisman and Schumacher, 1940). This technique is based upon the assumption that the ground area occupied by a tree is related to dbh by a second-degree parabola. Since the density of stocking is determined by the total of the growing spaces of the individual trees, the space utilized on a per-acre basis can be expressed by the general formula:

$$Y = aN + b\Sigma D + c\Sigma D^2$$

where Y is the tree-area ratio or growing space in milacres, N is the number of trees per acre, and D is dbh in inches. This technique provides a measure of density readily usable for uneven-aged stands and is largely independent of age or site index. Chisman and Schumacher used data from

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USDA Misc. Pub. 50 (1929) to derive an equation for so-called "normal" stands of southern pine. Their formula predicts 213 twelve-inch trees, 709 six-inch trees, or 7,067 one-inch trees for 100 percent stocking. These figures were considered too high, so it was decided to follow criteria outlined in the U.S. Forest Service Handbook. The following tabulation shows the density standard in terms of trees per acre, by size class, required for 100 percent stocking:

DBH In.	Trees/Acre No.	DBH In.	Trees/Acre No.
Seedlings	600	16	72
2	560	18	60
4	460	20	51
6	340	22	42
8	240	24	36
10	155	26	31
12	115	28	27
14	90	30	24

Using data in the above tabulation, a formula was fitted to give estimates of the tree-area ratio. In deriving the formula, the dbh of seedlings was considered as 0.0, and midpoints of 1-inch diameter classes were used. The fitted equation, based on the above criteria, was:

$$\text{Tree-area ratio} = 1.6667 + 0.0404D + 0.0434D^2$$

This formula was used for the following studies.

Study Installation

One of the studies was installed on uneven-aged loblolly-shortleaf pine-hardwood stands in Ashley County, Arkansas. Site index for loblolly pine is about 95 feet at age 50. A second study was installed in uneven-aged stands in Nevada and Ouachita counties. Site index for loblolly in this study is about 80 feet. There were fewer hardwoods and underbrush on the Nevada-Ouachita County plots than on the Ashley County plots, probably because of the lower site index.

Stocking levels of 10, 20, 30, 40, and 50 percent were established on square, 1-acre plots, with one-half acre interior measurement plots. Following a preliminary inventory of the study areas, all trees larger than 12 inches dbh were logged from plots during the dormant 1979-80 season. Trees in the smaller dbh classes were subsequently removed until the prescribed stocking level was reached. Remaining trees ranged from 12 inches dbh to seedlings and were selected for uniformity of distribution. An effort was also made to select adequate numbers of stems in each 1-inch diameter class to approximate a Q-factor of 1.2 to 1.3. Theoretical and actual numbers of stems on two study plots (10 and 50 percent) are shown in table 1.

All hardwoods were injected with Tordon 101 in the spring of 1980. The only future management practice anticipated other than hardwood control will be fire protection. Pines reproduced on buffer strips will be allowed to remain, but reproduction on the interior measurement plots will be removed at periodic intervals. Thus, future determinations of stocking levels will take into account only those trees growing on plots when the studies were installed.

Stocking levels, based on the aforementioned tree area ratio, will be determined after 2 and 5 years. Increases in stocking levels will be determined for all plots after each of these periods. Regression analyses will be used to predict stocking after a specified interval, based on initial stocking; percent stocking after the specified interval will be plotted over initial stocking.

Results of these studies should tell how poorly stocked a stand may be and subsequently recover after being placed under management.

LITERATURE CITED

Chisman, H. H. and F. X. Schumacher. 1940. On the tree-area ratio and certain of its applications. Jour. For. 38: 311-317.

U.S. Department of Agriculture. 1929. Volume, yield, and stand tables for second-growth southern pines. Misc. Pub. No. 50.

Table 1.--Theoretical and actual numbers of stems per acre for two representative study plots with 10 and 50 percent stocking.

	50 % Stocking		10 % Stocking	
Dia. Class	Theoret.[1]	Actual[2]	Theoret.[1]	Actual[3]
Inches	No.	No.	No.	No.
Seedlings	48	34	10	12
1	36	20	7	8
2	28	34	6	6
3	22	44	4	2
4	17	16	3	2
5	13	6	3	-
6	10	10	2	-
7	8	10	2	-
8	6	8	1	2
9	4	6	-	2
10	3	4	1	2
11	3	-	-	-
12	2	2	1	2
Total	200	194	40	38

1/ Q-factor of 1.30

2/ Q-factor of 1.26

3/ Q-factor of 1.14

REGULATION OF UNEVEN-AGED LOBLOLLY-SHORTLEAF PINE FORESTS [1]

Robert M. Farrar [2]

Abstract.--Briefly reviews regulation of loblolly-shortleaf pine forests managed under the selection system. Presents two alternative techniques of regulation with some advantages and disadvantages of both. Reports the current effort on regulation research at the Monticello/Crossett Project.

Historically, the selection system has had its ups and downs in this country; and, with few notable exceptions, it has never received the interest given even-aged systems. Perhaps this is because the majority of our most economically important timber types are principally composed of more or less intolerant species and generally well-suited to even-aged silvicultural systems, which in turn may be more efficient for large scale operations. However, there are probably few timber species in the country that cannot be managed under some form of the selection system--including longleaf pine with cyclical burning. But, the process might not be as efficient for some particularly intolerant species as an even-aged system. Past research has shown that the loblolly-shortleaf pine type can be managed rather easily under a selection system. Some form of the selection system may provide an attractive alternative for the non-industrial landowner who possesses few acres, wants to manage his existing stand to obtain reasonable returns in his lifetime, and is unable or unwilling to incur large capital costs associated with certain even-aged management techniques.

Currently, the main drawbacks to selection management seem to be (1) a general unawareness or misconception of the system, (2) vague perceptions of the system as a threat to established policies and operations, and (3) some truly inherent problems regarding: (a) the need for more elaborate inventory details, (b) possible dis-genic effects from mis-application, and (c) perceived difficulties in application of certain area-wide treatments such as prescribed burning. The first drawback, unfamiliarity, can be overcome by reference to good silviculture and management texts (i.e., Smith 1962, Davis 1966) and current literature, and through information exchange with foresters who have effectively practiced the system. The second, variance with established operations, should not exist at all because we need to have a full complement of alternative silvicultural and management techniques at our disposal if we are to do justice to our clients and ourselves as professionals. The last group of problems is real but each can be minimized.

DEFINITIONS PERTAINING TO UNEVEN-AGED MANAGEMENT

A few working definitions for this paper's purpose are:

Regulated forest = one where age and/or size classes are represented and growing such that nearly equal periodic yields of desired products are obtained. It may be composed of even-aged stands, uneven-aged stands or both.

Uneven-aged stand = one that contains 3 or more distinct age (size) classes. In practice it is a stand that exhibits a d.b.h. distribution tending towards a "reverse-J" in shape rather than the mound-shaped curve typical of an even-aged stand. It has no start or end point in time.

Balanced uneven-aged stand = one whose d.b.h. distribution closely follows a negative exponential probability density function (reverse-J). The ratio of numbers of trees in succeeding d.b.h. classes is a constant (called Q); $N_i/N_{i+1}=Q$.

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[1] Presented at the Southern Silvicultural Research Conference, Atlanta, GA., Nov. 6-7, 1980.

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The exponential p.d.f. is: $f(x) = re^{-r(x)}$ where x = d.b.h. and $Q = e^{rw}$ where w = d.b.h. class width.

The functional form is: $N_i = e^{b_o} e^{b_1(D_i)}$ or $\ln(N_i) = b_0 + b_1(D_i)$ where N_i & D_i = number of trees in ith d.b.h. class and $Q = e^{b_1 w}$.

Irregular uneven-aged stand = one whose d.b.h. distribution does not closely follow a negative exponential distribution (the Q is not a constant).

Selection system = any silvicultural program aimed at the creation or maintenance of uneven-aged stands.

Selection method = Activities employed for the regeneration of uneven-aged stands. There are several recognized modifications of the selection method: single tree = removal of 1 or few trees for regeneration

group = removal of small patches of trees

strip = similar to strip shelterwood or clearcut

Dauerwald = similar to single tree but no thought given to regeneration

diameter-limit = removal of all trees in and/or above a specified diameter

"economic" selection or "selective cutting" = not a valid method = high-grading

Selection and even-aged systems can be viewed as a closed continuum, i.e., single tree selection can grade into irregular shelterwood, while group selection can approach patch clearcutting. The key distinction is related to area-wise age distribution and record-keeping. For example, if records on tree age (or size) are kept on a tree to tree basis, then the selection system is indicated. If records on tree age (or size) are maintained on an area basis, then an even-aged system is probably being used.

PAST

A history and status report of selection management in this country can be found in the proceedings of a workshop conducted by the Forest Service (1978). A few points brought out at that workshop should be emphasized. The French forester de Liocourt observed that the number of trees in successive d.b.h. classes in an uneven-aged forest tended to decrease in a smooth geometric progression and this progression was apparently stable through time (Meyer 1952). In other words, Q tended to be a constant with time. A number of foresters have made contributions to uneven-aged forest management in various parts of this country. Meyer and Stephenson (1943) noted that the d.b.h. distributions of virgin northern hardwood forests in Pennsylvania tended to have a constant Q and that the structures were also apparently stable through time. Pearson (1950) employed a variation of the selection system in the management of ponderosa pine in the Southwest. Several workers in the U.S. Forest Service's Northeastern Station territory have applied the selection system to various forest types on an experimental basis. They have significantly contributed methods for inventorying and objectively describing and prescribing the structure for selection stands (Leak 1963, 1964, 1965; Trimble et al. 1974; Trimble and Smith 1976; Marquis 1978). Several Western workers have discussed applications and modifications of these techniques in certain coniferous types (Alexander and Edminster 1977 a & b, Hann and Bare 1979). In the South, the most notable contributors to selection management have been Reynolds (1959, 1969), working with loblolly-shortleaf pine stands in southeastern Arkansas, and Brender (1973), working with loblolly pine in the Georgia Piedmont.

This discussion deals with data and derived functions from selection-managed stands in southeastern Arkansas and the application of regulation techniques employed by Reynolds in the Southern Station and suggested by Northeastern Station research.

PRESENT

In uneven-aged management, the cutting cycle replaces the even-aged rotation as an operating control. If a 10-year cutting cycle and an annual cut are desired, the property is divided into 10 equally productive areas and one area is cut each year. Stands are not classified by average age or tree size but by d.b.h. distribution and volume (stand and stock table) and species composition. At our present stage of research at Monticello/Crossett we consider that we have essentially one species--pine--composed principally of loblolly with a minority of shortleaf (about 1/3 of the volume). So, we deal with the pine stand and stock table in regulation activities.

We presently have one operable technique for regulation with which we have had experience--plus some associated local volume prediction and projection equations which allow us to look at various options. This technique is essentially regulation through volume control in the sawtimber component of the stands using a "guiding d.b.h. limit". Briefly, it works as follows: First, you need an inventory by d.b.h. classes and a local or other volume-defining function to generate an observed stand and stock table. Then you decide upon a cutting cycle, how much volume your stand should have at the end of the cycle, and at what rate the stand is expected to grow. For example, if 7000 fbm (Doyle) volume is desired at the end of a 5-year cutting cycle, and the stand is expected to grow at a 6% compound rate, then the residual stand volume is calculated as $7000/(1.06)^5$ or

5231 fbm. If the stand presently has, say, 9952 fbm, the cut is 4721 fbm (9952-5231). A volume of 1769 fbm (7000-5231) should be restored by expected growth in 5 years to result in 7000 fbm standing at the end of that period. A stand containing about 7000 fbm (Doyle), 1400 cubic feet in sawtimber, 2000 merchantable cubic feet, and 75 square feet of basal area is considered by Reynolds [1] to be a general or working optimum at the end of a cutting cycle for south Arkansas and north Louisiana. If the stand initially contains less volume, the cut should be proportionally less to allow for an increase in stocking.

Once the cut volume is determined, volumes are accumulated by d.b.h. class, starting with the largest, until a volume equal to the proposed cut is reached (see table 1). The d.b.h. class where this volume is reached is the "guiding d.b.h. limit" (g.d.l.). The general plan is to cut all trees with d.b.h. equal to or larger than the g.d.l. until the allowable cut is reached. In practice, however, larger trees are left if they are growing well and less desirable smaller trees are substituted. The principal objective is to keep the sawtimber component producing at a good rate. The sub-sawtimber component is not regulated but thinned according to silvicultural need. Silvicultural experience is very valuable in this activity if a sufficient ingrowth reservoir is to be maintained to supply future harvests. No particular attention is paid to regeneration because, in this area, loblolly seeds prolifically and normal cutting and logging disturbance provides adequate space and seedbed requirements--_if_ hardwoods are kept under control. This system closely resembles the classical Dauerwald system of Europe where regeneration received no consideration. In actual practice however, attempting to apply a selection system without some provision for regeneration is like attempting to develop a perpetual motion machine--it is impossible. Periodic regeneration is the necessary basic input that sustains the system.

In order to facilitate prediction of volume growth responses from differing density and cutting cycle regimes, we have developed a system of cubic-foot volume prediction and projection functions (Murphy and Farrar 1980) from long-term studies of regulation at Crossett. The equation system consists of a stand volume predictor and a basal area projector using initial basal area and elapsed time as the input variables and is based on the technique of Moser and Hall (1969). Examples of how this equation system can be used are illustrated in Figures 1 and 2. In the first example, a 3-, 6-, or 9-year cutting cycle is employed with the aim of having the same basal area (or volume) at the end of each cycle. In each case, the stand will have grown back to a density level of 75 square feet of basal area during the interval between harvests. The second example illustrates cutting to a constant basal area (60 square feet) on a 3-, 6-, or 9-year cutting cycle. Table 2 shows the periodic annual increment (p.a.i.) from these exercises over an 18-year period and suggests that little difference can be attributed to cutting cycle length for these examples. Reynolds' (1969) results from maintenance of these cutting cycles for about 30 years on a total of 24 forty-acre compartments supports the same trend.

Table 1.--Example of cut volume determination in a selection stand regulated by "volume-guiding diameter limit" (per acre).

DBH	No. Trees	Merch. Vol.	Board-foot Volume		
	--before cut--		before cut	cumul.cut	after cut
(in.)		(ft^3)	--------(fbm,Doyle)----------		
4	17.1	9			
5	15.6	28			
6	13.2	45			
7	10.0	54			
8	8.5	67			
9	5.6	60			
10	6.0	84	169		169
11	6.7	119	265		265
12	5.9	129	329		329
13	4.3	114	329		329
14	6.1	195	631		631
15	4.0	149	533		533
16	5.3	230	898		898
17	4.5	224	944		944
18	3.2	180	809		809
19[1]	3.5	219	1047	4721	327
20	1.3	94	474	4001	
21	1.6	125	663	3527	
22	1.2	103	573	2864	
23	1.1	100	582	2291	
24	0.9	96	577	1709	
25	0.1	15	93	1132	
26	0.1	16	104	1039	
27	0.3	34	231	935	
28	0.3	36	255	704	
29	0.3	38	281	449	
30	0.0	0	0	168	
31	0.1	21	168	168	
	126.8	2584	9952	4721	5231

[1] guiding d.b.h. limit

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[1] R. R. Reynolds, personal communication, 1979

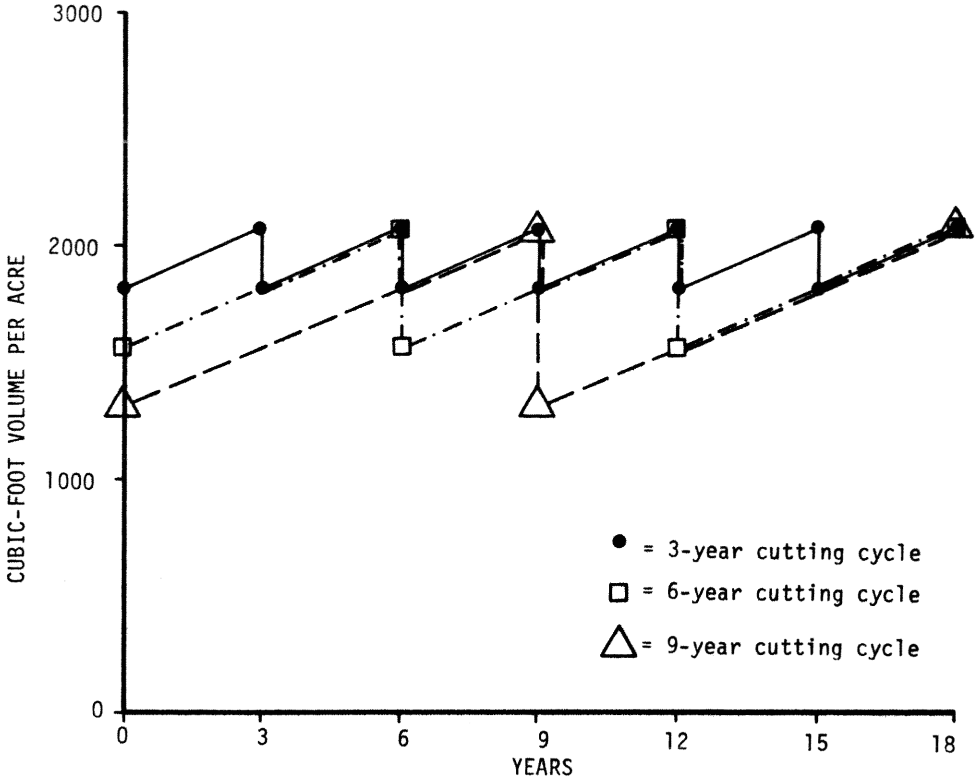

Figure 1.--Predicted stand volumes and removals for loblolly-shortleaf selection stands managed under three cutting cycles, 75 sq. ft. final basal area, SI=90 class.

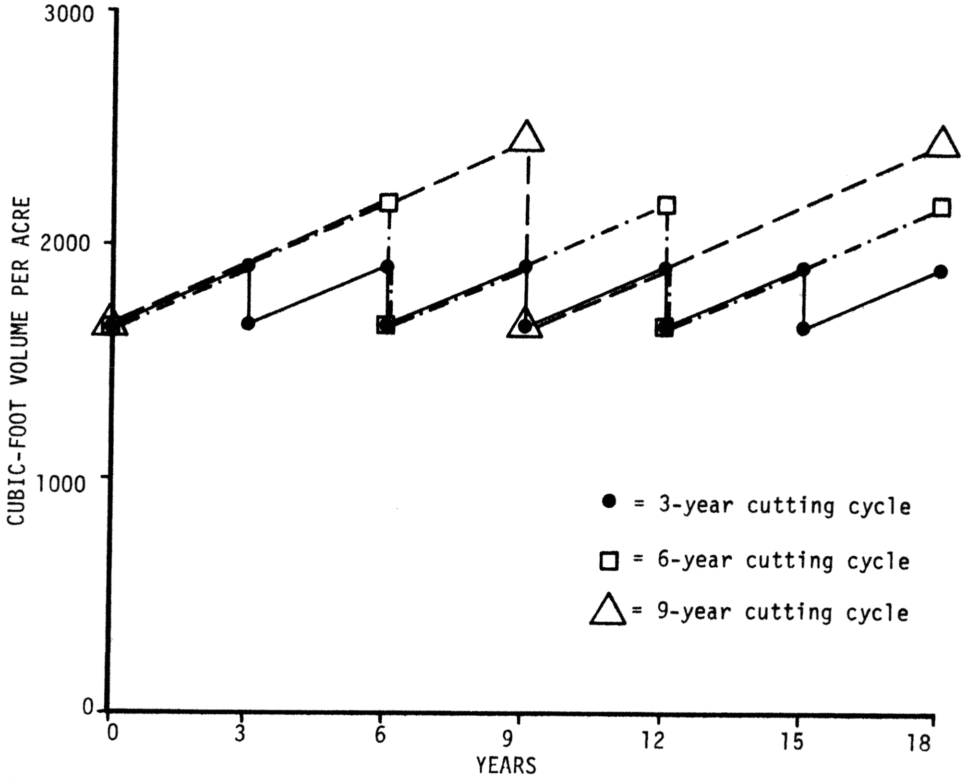

Figure 2.--Predicted stand volumes and removals for loblolly-shortleaf selection stands managed under three cutting cycles, 60 sq. ft. initial basal area, SI=90 class.

Table 2.--Observed and predicted Periodic Annual Increment (P.A.I.) for selection stands of loblolly-shortleaf managed under 3-, 6-, and 9-year cutting cycles, SI=90 class.

Cutting Cycle	Observed (Reynolds 1969)		Predicted			
			Constant 75 Final BA		Constant 60 Initial BA	
(years)	Period (years)	P.A.I. (ft.^{3})	Period (years)	P.A.I. (ft.^{3})	Period (years)	P.A.I. (ft.^{3})
3	27	85.7	18	87.7	18	85.0
6	24	84.5	18	85.7	18	87.0
9	21.4	82.0	18	83.2	18	88.3

Note that the equation system allows simulation of many more regulation schemes than those shown (i.e., increasing or decreasing basal area, varying the cutting cycle within a regime, etc.). Our next step here with this system is to extend it to sawtimber volume prediction and projection and to site indices other than the 90 class.

FUTURE

Experience suggests that the "volume-g.d.l." regulation technique will allow us to adequately regulate selection stands principally for sawtimber volume production for considerable periods of time. Simplicity is its greatest virtue. As long as conditions are similar to those studied at Crossett, our stand basal area and cubic-foot equation system will allow us to predict the initial and final volumes for a considerable array of conditions and anticipated improvements in the system should greatly extend its utility.

However, a few problems remain. One is lack of objectivity in prescribing the structure of the residual stand, particularly the sub-sawtimber component, and another is predicting the size-class distribution of volume in the future structure. The "volume-g.d.l." technique, including the stand basal area and volume predictors, has little predictive ability regarding stand and stock tables. We think for both problems we have a single solution that will provide interim guidelines for regulation. It is employment of the NE Station "basal area-maximum d.b.h.-Q" or BDQ technique for objectively prescribing a residual structure for a selection stand. The elements of BDQ are: the residual basal area (B) that you desire, the maximum tree dbh (D) that you elect to leave, and the ratio (Q) between the numbers of trees in succeeding d.b.h. classes that you select. If you know these three factors and have a volume-defining function, you can generate a stand and stock table for any combination of these 3 factors. The software is easy to develop for computers, including programmable hand-held models. However, computer capability is not at all necessary to employ BDQ (see Marquis 1978).

Starting with an observed stand and stock table from an inventory (table 3), you can generate a target residual structure using the BDQ technique (after Marquis 1978). Basically, this entails distributing the desired residual basal area between specified minimum and maximum d.b.h. classes according to a Q. Table 4 shows a target stand and stock table generated for a B=60, D=22, Q=1.155 and figure 3 shows the d.b.h. distributions. By subtracting the target from the inventory you then know rather precisely how many trees are to be cut and left in each d.b.h. class. If basal area is lacking in some classes you can leave extra basal area in smaller classes. All you have to do is find the trees; cut the worst and leave the best in each class. This is a great advantage for foresters who might like to apply the selection system but do not have experience with it. In field application, the objectivity of this technique is the principal improvement over the "volume-g.d.l." technique where considerable subjectivity is employed in treating the sub-sawtimber component. Also, the entire stand is regulated rather than just one component and this is important if area is to be efficiently utilized and ingrowth reservoirs maintained. Given a reasonably good choice of B, D, and Q, you have an objective means of prescribing the residual stand and the cut. You have some assurance that you have created a reasonably good residual structure for a selection stand even if you have not had extensive experience with selection systems.

This does not mean that we are home free. At present, all we have is circumstantial evidence of the utility of the BDQ technique. As far as I know, it has not been tested rigorously in southern pine stands. However, we do have a good starting point. From the historical records of selection system research, we know that the Q for 1-inch classes hovers around 1.2 (figure 4) for the Crossett stands. This is particularly encouraging because these stands were not regulated by BDQ and residual densities and maximum diameters were not constant within a cutting cycle. We also have evidence as to what the residual basal area (B) should be for cutting cycles of 3 to 10 years for conditions near

Reynolds' working optimum. Further, we can also select a maximum d.b.h. (D) that (in conjunction with B, Q, and estimated B and D growth) will generate initial and final structures that closely approximate Reynolds' optimum basal area and volumes (Tables 4 and 5, Figure 5). Obviously, the next step is to experimentally regulate a series of stands by BDQ and determine the response of basal area, maximum d.b.h., and Q over time. We have initiated research toward this end and will soon have 66 stands experimentally regulated under BDQ (table 6). We are confident we can predict future basal areas, and maximum d.b.h. should be predictable from increment cores or, better, from stand parameters and elapsed time. Hopefully, an established Q will essentially remain constant over time but, if not, it should change in a fashion predictable by stand parameters and elapsed time. Given all this plus a tree height predictor and a volume-defining function (i.e., integrated taper function), we then have the components of a stand and stock table predictor and projector for the regulation of selection stands of loblolly-shortleaf that are managed using BDQ.

Table 3.--An observed stand and stock table for a selection stand of loblolly-shortleaf, SI=90 class.

```
Type of inventory: BEFORE-CUT                    INVENTORY SUMMARY
Compartment: SELECTION 2                  SOUTHERN FOREST EXPERIMENT STATION
Study: CUT METHODS                             RWU-SO-1117, MONTICELLO
Species; LOB-SHORT
Date: APR.79
Acreage:   7.5


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DBH       TPA     BA/A      MERCV     SAWCV     TOPCV     DOYLE    INT/4    SCRIB

                                  PER ACRE

  1      0.00     0.00        0.0       0.0       0.0         0        0        0
  2      0.00     0.00        0.0       0.0       0.0         0        0        0
  3      0.00     0.00        0.0       0.0       0.0         0        0        0
  4     17.07     1.49        8.7       0.0       0.0         0        0        0
  5     15.60     2.13       27.7       0.0       0.0         0        0        0
  6     13.20     2.59       45.0       0.0       0.0         0        0        0
  7     10.00     2.67       54.4       0.0       0.0         0        0        0
  8      8.53     2.98       67.3       0.0       0.0         0        0        0
  9      5.60     2.47       60.2       0.0       0.0         0        0        0
 10      6.00     3.27       84.4      40.4      44.0       169      311      160
 11      6.67     4.40      118.8      75.2      43.5       265      535      389
 12      5.87     4.61      129.1      92.4      36.7       329      635      517
 13      4.27     3.93      113.7      86.5      27.2       329      585      500
 14      6.13     6.56      194.6     153.4      41.2       631     1029      903
 15      4.00     4.91      148.9     120.1      28.8       533      804      716
 16      5.33     7.45      230.1     189.1      41.1       898     1270     1140
 17      4.53     7.15      224.2     187.4      36.8       944     1267     1143
 18      3.20     5.65      179.7     152.7      26.9       809     1041      944
 19      3.47     6.83      219.0     189.4      29.6      1047     1305     1188
 20      1.33     2.91       94.0      82.8      11.2       474      577      528
 21      1.60     3.85      125.0     112.2      12.9       663      790      727
 22      1.20     3.17      103.2      94.3       8.9       573      672      622
 23      1.07     3.08      100.3      93.3       7.0       582      673      627
 24       .93     2.93       95.5      90.3       5.2       577      659      618
 25       .13      .45       14.7      14.2        .6        93      105       99
 26       .13      .49       15.9      15.4        .4       104      116      110
 27       .27     1.06       34.0      33.4        .5       231      254      243
 28       .27     1.14       36.2      36.0        .2       255      276      267
 29       .27     1.22       38.3      38.3       0.0       281      298      292
 30      0.00     0.00        0.0       0.0       0.0         0        0        0
 31       .13      .70       21.2      21.2       0.0       168      171      170

       126.80    90.09     2584.2    1918.0     402.9      9952    13373    11902


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Table 4.--A BDQ after-cut target stand and stock table, SI=90 class.

```
     Type of Inventory :AFTER-CUT TARGET                      TARGET STAND SUMMARY
     Compartment Number :SELECTION 2                       SOUTHERN FOREST EXPERIMENT STATION
     Study :CUT METHODS                                          RWU-1117, MONTICELLO
     Species :LOB-SHORT
     Date :APR.79

     Minimum DBH:  1
     Maximum DBH:  22
     Q Ratio : 1.155
     DBH Class Width : 1
     Exponent on DBH : 1
     Basal Area per Acre : 60

********************************************************************************

DBH      TPA     BA/A     MERCV    SAWCV    TOPCV    DOYLE   INT/4   SCRIB

                                 Per Acre

  1    22.66      .12      0.0      0.0      0.0       0       0       0
  2    19.62      .43      0.0      0.0      0.0       0       0       0
  3    16.98      .83      0.0      0.0      0.0       0       0       0
  4    14.71     1.28      7.5      0.0      0.0       0       0       0
  5    12.73     1.74     22.6      0.0      0.0       0       0       0
  6    11.02     2.16     37.6      0.0      0.0       0       0       0
  7     9.54     2.55     51.9      0.0      0.0       0       0       0
  8     8.26     2.88     65.1      0.0      0.0       0       0       0
  9     7.15     3.16     76.9      0.0      0.0       0       0       0
 10     6.19     3.38     87.1     41.7     45.4     174     321     165
 11     5.36     3.54     95.5     60.5     35.0     213     431     313
 12     4.64     3.65    102.2     73.1     29.1     260     503     409
 13     4.02     3.71    107.1     81.5     25.6     310     551     471
 14     3.48     3.72    110.4     87.0     23.4     358     584     512
 15     3.01     3.70    112.2     90.5     21.7     401     606     539
 16     2.61     3.64    112.6     92.5     20.1     439     621     558
 17     2.26     3.56    111.7     93.4     18.4     470     631     570
 18     1.96     3.46    109.8     93.3     16.5     494     636     577
 19     1.69     3.33    107.0     92.5     14.4     511     637     580
 20     1.47     3.20    103.4     91.1     12.3     522     634     580
 21     1.27     3.05     99.2     89.0     10.2     526     627     577
 22     1.10     2.90     94.5     86.3      8.2     525     616     570

      161.75    60.00   1614.5   1072.5    280.3    5204    7398    6421


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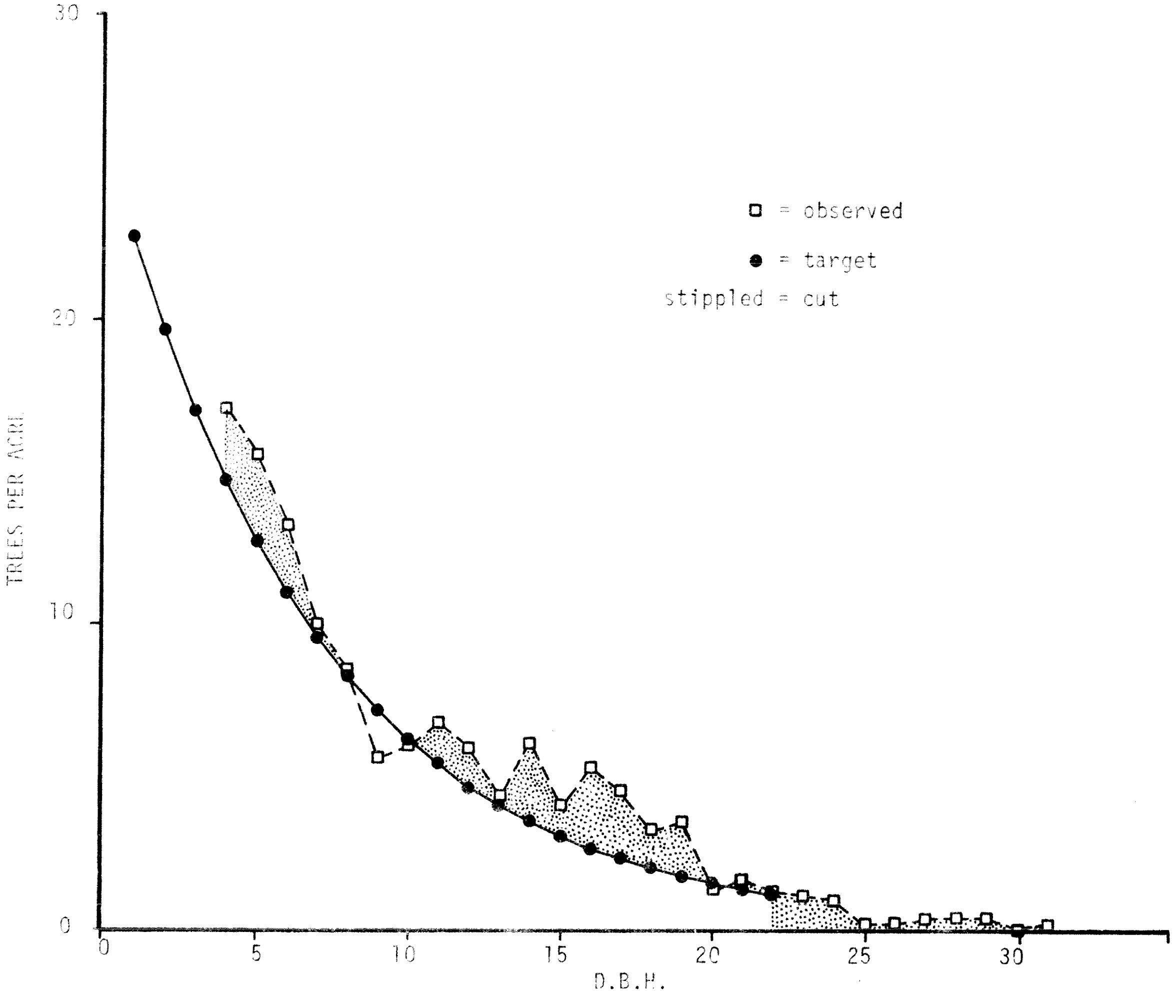

Figure 3.--Observed and after-cut target d.b.h. distributions for a selection stand of loblolly-shortleaf, SI=90 class.

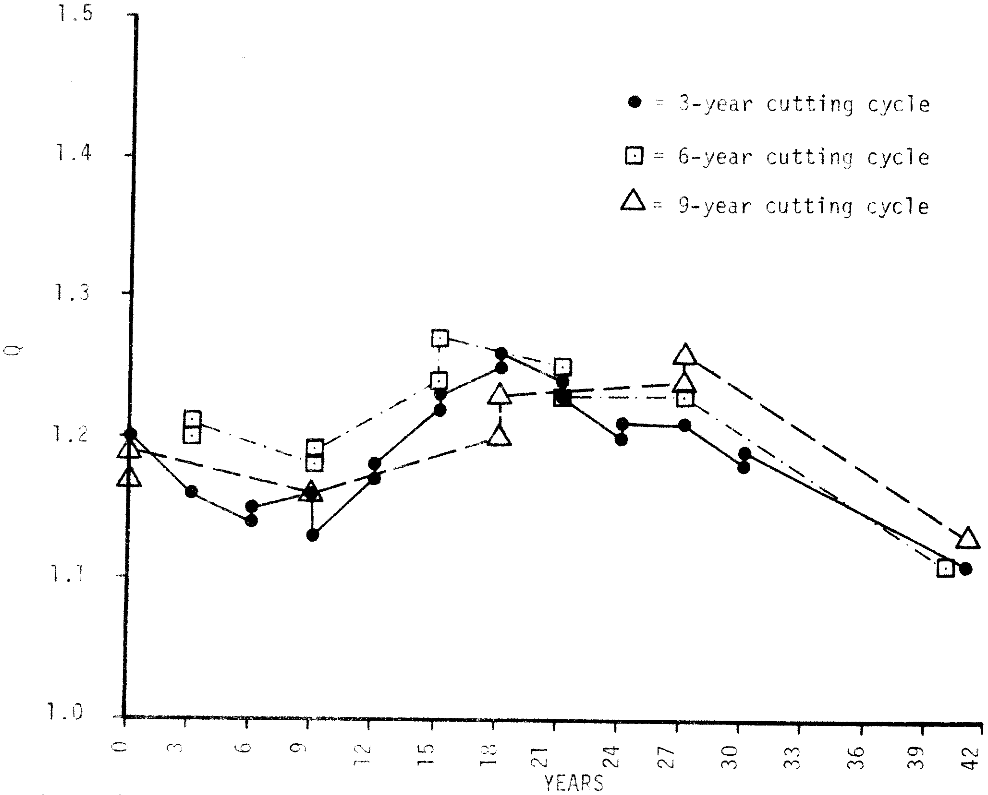

Figure 4.--Observed trends in fitted Q for selection stands of loblolly-shortleaf managed on three cutting cycles, SI=90 class.(3 reps. per c.c.).

Table 5.--Five-year BDQ projection of an optimum after-cut structure, SI=90 class.

```
   Type of Inventory :BEFORE-CUT PROJ.              TARGET STAND SUMMARY
   Compartment Number :SELECTION 2            SOUTHERN FOREST EXPERIMENT STATION
   Study :CUT METHODS                               RWU-1117, MONTICELLO
   Species :LOB-SHORT
   Date :APR.84


   Minimum DBH:   1
   Maximum DBH:   24
   Q Ratio : 1.155
   DBH Class Width : 1
   Exponent on DBH : 1
   Basal Area per Acre : 75
*********************************************************************

DBH      TPA      BA/A     MERCV     SAWCV     TOPCV     DOYLE   INT/4    SCRIB

                                 Per Acre

  1     26.01      .14       0.0       0.0       0.0         0       0        0
  2     22.52      .49       0.0       0.0       0.0         0       0        0
  3     19.50      .96       0.0       0.0       0.0         0       0        0
  4     16.88     1.47       8.6       0.0       0.0         0       0        0
  5     14.62     1.99      25.9       0.0       0.0         0       0        0
  6     12.65     2.48      43.2       0.0       0.0         0       0        0
  7     10.96     2.93      59.6       0.0       0.0         0       0        0
  8      9.49     3.31      74.8       0.0       0.0         0       0        0
  9      8.21     3.63      88.3       0.0       0.0         0       0        0
 10      7.11     3.88     100.0      47.8      52.2       200     368      190
 11      6.16     4.06     109.7      69.5      40.2       245     494      359
 12      5.33     4.19     117.3      84.0      33.4       299     577      469
 13      4.61     4.25     123.0      93.6      29.4       356     633      541
 14      4.00     4.27     126.8      99.9      26.9       411     670      588
 15      3.46     4.25     128.8     103.9      24.9       461     696      619
 16      3.00     4.18     129.2     106.2      23.1       504     713      640
 17      2.59     4.09     128.3     107.2      21.1       540     725      654
 18      2.25     3.97     126.1     107.1      18.9       567     731      662
 19      1.94     3.83     122.8     106.2      16.6       587     732      666
 20      1.68     3.67     118.7     104.5      14.1       599     728      666
 21      1.46     3.50     113.9     102.1      11.7       604     720      662
 22      1.26     3.33     108.5      99.1       9.4       603     707      654
 23      1.09     3.15     102.8      95.5       7.2       596     690      642
 24       .95     2.97      96.7      91.5       5.3       585     668      626

       187.72    75.00    2052.8    1418.2     334.3      7155    9850     8639
*********************************************************************
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CONCLUSION

Some progress has been made in research on regulation of uneven-aged loblolly-shortleaf pine forests, but by no means has the final answer arrived. We look at our prediction and projection systems for selection stand regulation as approximations. We can regard the "volume-g.d.l." technique as stage 1, our stand-level basal area and volume predictors and projectors as stage 2, and adaptation of the BDQ system will probably be stage 3, and stage 4 will probably be similar to stage 3 except that non-constant Q or more flexible distribution functions (i.e., truncated Weibull) will be employed, if necessary. These may be required so that we can more closely characterize and predict for those residual d.b.h. distributions that do not closely approach an exponential. We may find that d.b.h. distributions other than the simple exponential are more efficient for certain growth and production objectives. But, whatever d.b.h. distribution shape is chosen, it must be sustainable, within limits, over time; which means that it must allow for adequate periodic regeneration and subsequent ingrowth.

Table 6.--Selection stands contributing data on objective regulation via BDQ technique.

Name	Species	SI[1/] (ft.)	BA (ft.^{2})	DMAX (in.)	Q	Reps. (no.)	Approx. Rep. Size (ac.)
Ouachita	short.	60	60	18	1.2	3	10
Ark-907	lob.-short.	80	60	20	1.2	3	10
U.A.M.	lob.-short.	80	50	22	1.1	2	10
U.A.M.	lob.-short.	80	50	22	1.3	2	10
LMS, PSSF	lob.-short.	70	60	20	1.2	1	10
	lob.-short.	70	50	15	1.2	1	10
	lob.-short.	70	40	10	1.2	1	10
LMS, CEF	lob.-short.	90	60	22	1.2	1	10
	lob.-short.	90	50	16	1.2	1	10
	lob.-short.	90	40	10	1.2	1	10
E- A Conv., CEF	lob.-short.	90	60	16	1.2	2	5
BA-Burn, CEF	lob.-short.	90	100	18	1.2	12	2
	lob.-short.	90	80	18	1.2	12	2
	lob.-short.	90	60	18	1.2	12	2
	lob.-short.	90	40	18	1.2	12	2
						66	

[1/] site index at age 50, loblolly except for Ouachita shortleaf stands

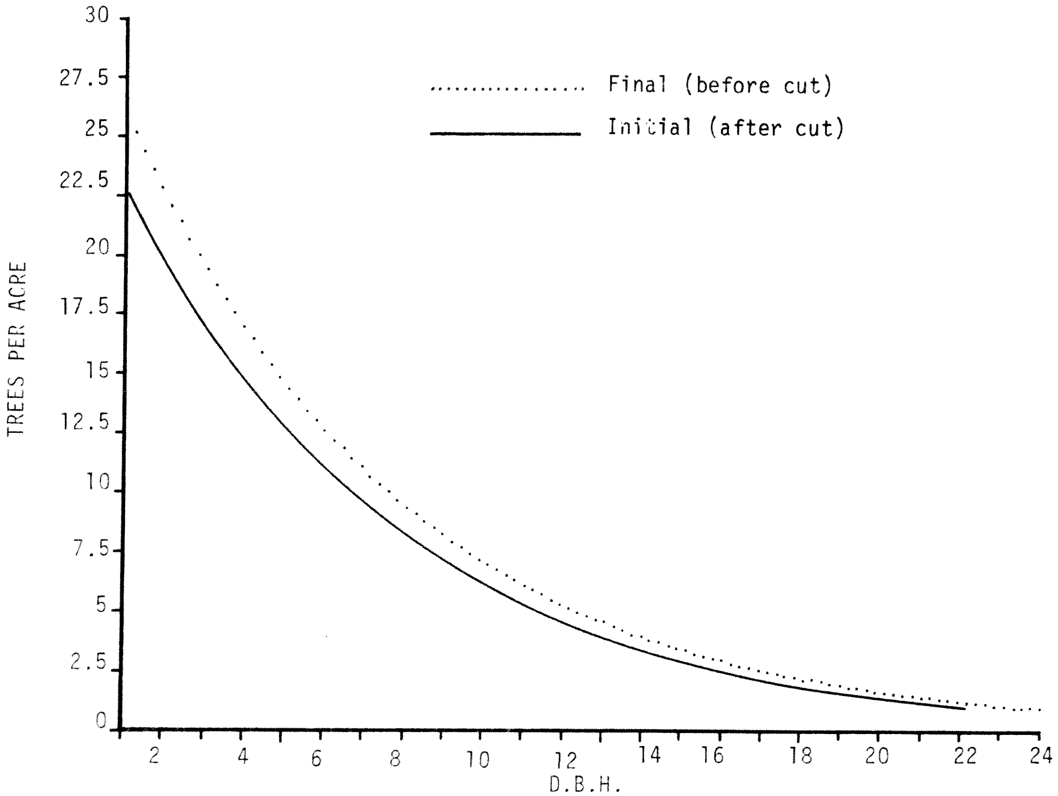

Figure 5.--BDQ d.b.h. distributions approximating optimum structures for loblolly-shortleaf selection stands using a 5-year cutting cycle, SI=90 class.

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GROWTH AND YIELD OF UNEVEN-AGED LOBLOLLY-SHORTLEAF PINE STANDS--A PROGRESS REPORT [1]

Paul A. Murphy [2]

Abstract.--Although uneven-aged growth and yield has been a neglected topic, some potentially useful approaches have been developed. Following is a synopsis of research-in-progress at Monticello/Crossett in applying these approaches and developing others.

INTRODUCTION

Much less information is available on the growth and yield of uneven-aged stands than on that of even-aged ones. Most forest management organizations have chosen even-aged management for several reasons; for example, silvicultural tasks can be administered efficiently, there is already a large investment in tree improvement programs, fire can be used as a silvicultural tool, and even-aged management usually needs less technical expertise.

But interest in uneven-aged management as a practical alternative has recently revived, particularly for private nonindustrial ownerships in the loblolly-shortleaf pines of the South. Fortunately, research done elsewhere on uneven-aged growth and yield is a reservoir of experience and expertise. Some of this information has recently been summarized (U.S. Forest Service 1978, Hann and Bare 1979).

STATUS OF PRESENT KNOWLEDGE

Structural Description

Stand structure is important in management of uneven-aged stands. Stand structure can be defined as the number and distribution of trees per unit area by species, age, size, spacing, or other attributes. Here it is the distribution of trees by dbh classes. The French forester de Liocourt observed that the number of trees in successive dbh classes usually forms a smooth geometric progression (Meyer and Stevenson 1943, Meyer 1952), which can be represented graphically by a reverse J-shaped curve. The ratio of the number of trees in a given dbh class to the number in the adjacent higher class was usually constant. This ratio is called "Q". Meyer and Stevenson (1943) graphically fitted the logarithmic form of the reverse-J or exponential function to several virgin beech-birch-maple-hemlock forests in Pennsylvania and found that these stands usually followed a constant Q. later attempts at describing uneven-aged stand structure have focused on using some variant of the Q concept.

Leak (1963, 1964) showed how Q can be calculated by least squares and developed a technique for describing stand structure where Q values vary by dbh classes. He later (1965) emphasized that the exponential (sometimes called negative exponential) probability density function pdf could be used to describe uneven-aged stand dbh distributions and that the parameter of the distribution was functionally related to Q. Moser (1976) showed how a dbh distribution can be specified for a given exponential function, maximum tree size, and density--with density stated as basal area, tree-area ratio, or crown competition factor. To date, no one has tested the exponential pdf by empirically fitting it to stand dbh frequency data and comparing it with actual stand tables.

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[1] Presented at the Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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Bailey and Dell (1973) fitted the Weibull pdf to uneven-aged stand data as an example and recognized that the exponential is a special form of the Weibull. In their example, the Weibull shape-parameter was fixed at 1 so they were fitting an exponential to the uneven-aged stand data rather than allowing the full Weibull to be estimated. Hyink and Moser (1979) fitted the three-parameter Weibull to uneven-aged hardwood dbh distribution data and modeled the change in the Weibull scale and shape-parameters over time. Stiff (1979) used the left-truncated two-parameter Weibull to represent dbh distributions of mixed-species Appalachian hardwoods.

In the past the exponential function has been used for providing a guide to desirable stand structure in uneven-aged stands. It is simple in concept and easy to apply. But it may not be possible to keep stands regulated to a Q structure, and a Q distribution may not be best for maximum growth. These problems are hypothetical and need to be proved or disproved by studies. The exponential has much precedence and attraction and is the logical candidate to test first.

Stand-Level Models

Some progress has been made in predicting growth and yield for uneven-aged stands. Moser and Hall (1969) formulated a growth and yield model for stand volume and stand basal area based on the principle that yield should be the integral form of the growth function. This idea had been used by Buckman (1962) and Clutter (1963) to develop equations for even-aged pine stands. The only variables they used were volume and basal area. Hyink and Moser (1979) developed a yield model based on predicted changes in the Weibull function fitted to dbh frequency data.

Moser later (1972) derived a system of first-order, ordinary differential equations for describing the components of net growth by basal area and number of trees. This system was later expanded (Moser 1974) to include different size classes.

Leary (1970) described how to predict survivor growth by size classes by using nonlinear ordinary differential equations for northern hardwood stands. Solution of these equations was based on the boundary values rather than least squares.

Ek (1974) formulated a series of nonlinear equations that described ingrowth, mortality, and survivor growth by dbh classes. Ingrowth was the number of trees growing into the smallest dbh class. The equations describing mortality and upgrowth were used for all size classes; there were no separate equations for each dbh class.

Stand table projection is a technique long used to make short-term forecasts of forest stands, both even- and uneven-aged. Wahlenberg (1941) is perhaps the best example of stand table projection techniques. A recent variant of stand table projection is the Markov chain approach: as in Peden, Williams, and Frayer (1973) and Bruner and Moser (1974).

Tree Level Models

The growth and yield models described so far have used either stand variables or variables that are aggregated values, such as number of trees by dbh class. Individual tree simulation is another approach to uneven-aged growth and yield modeling, in which the change in variables associated with individual trees is projected over time. Models of this type fall into two main groups--distance-independent and distance-dependent. The distance-dependent models use some measure of competition from neighboring trees. This measure is related to the distance between the simulated tree and the competitor tree. In distance-independent models, stand level attributes are used to modify the growth of the simulated tree. In both cases, attributes of the trees themselves are also used to model individual tree growth. The summation of the individual tree growth is stand growth. Most of these models have been developed for pure even-aged stands or plantations. There have been fewer attempts with mixed, uneven-aged stands.

Ek and Monserud (1974) developed a computer model called FOREST to simulate the growth and reproduction of plots in mixed species, even- or uneven-aged forest stands. The model incorporated tree size and inter-tree distances. Botkin, et al. (1972) developed a mixed species individual tree computer simulation model, in which the effect of other plot trees was defined in a variable that was the sum of the leaf areas of all the larger trees on the plot. Stage (1973) developed what was called a "prognosis model for stand development." It is a distance-independent tree growth simulator.

The advantages of stand-level versus individual tree models have been debated in recent years, and the general consensus seems to be that neither has better predictive power. The single-tree models provide a wealth of information, since they may be aggregated from the individual tree, but the cost of simulation with this type of model can be expensive. Costs, however, must be constantly re-evaluated because the rapid development of minicomputers is continually bringing down the cost of processing. The stand-level models offer the advantages of simplicity and low-cost simulation. Simplicity is not necessarily best, but it enables the observer to understand how the componants are working in relation to each other. The complexity of individual tree models can defy comprehension, sometimes even of the creator. Often choice of model may be dictated by the nature and form of the data.

For the initial investigation, Crossett Experimental Forest historical data going back to the late 1930's were available. The form of this information requires stand-level models, if these data are to be used. Also, it was felt that concentrating efforts in this direction will ultimately help in the development of single-tree models that may be needed in the future.

RESEARCH-IN-PROGRESS

This research program can be divided into three general areas: (1) prerequisite studies, (2) characterization of extant stand conditions, and (3) projection of the changes in these conditions over time with and without treatment.

Prerequisite Studies

Two studies were used in the area of preliminary research--investigations that are necessary for providing information needed as a basis for each research. The first study is the development of comprehensive tree volume and taper functions for naturally regenerated loblolly and shortleaf pines. Stem measurements of some 500 loblolly and shortleaf trees have been collected to date, and should total total about 600 when field measurements are completed. The results will enable researchers to calculate tree volumes for different merchantability standards and develop multiple-product yield estimates for trees and stands.

A study on how size of the research plot affects variability of selected stand variables was completed. The variables--basal area, number of trees, arithmetic mean diameter, quadratic mean diameter, sum of diameters, minimum diameter, and maximum diameter--were measured on plots varying by ¼ acre increments, from ¼ to 2 acres at 30 locations. Most coefficients of variation for these variables stabilized in the ½- to 1-acre range. These results will be used when the field studies are started.

Stand Characterization

The exponential or Q distribution has been used the most to describe uneven-aged stand structure and is the logical candidate for testing first. No one to date has rigorously tested whether the pdf form of the exponential is adequate in describing uneven-aged dbh distributions. Some 588 before-cut and 381 after-cut stand tables of uneven-aged loblolly-shortleaf pine (3.6 inches dbh and greater) managed under volume regulation were fitted to the left truncated and doubly truncated exponential pdf's. The doubly truncated assumes both a minimum and maximum dbh. The Kolmogorov-Smirnov one-sample test at the 5-percent level was used. Stands for these samples ran from 2.5 to 40 acres and can be considered as populations with known parameters. Rejection rates were 88 percent for before-cut and 89 percent for after-cut distributions fitted to the singly truncated form. The rejection rates for the doubly truncated ran 72 and 77 percent. Most rejections were due to deviations in the 4- to 9-inch dbh classes. The K-S test is rigorous because some stand tables exceeded 4000 trees. The slightly better performance of the doubly truncated exponential indicates that, perhaps, truncated forms should be looked at when other distributions are considered.

The stands used in this study were managed by the volume control method of stand regulation in which no particular emphasis is placed on maintaining or working towards a specified structure. The outcome could have been different if the stand had been managed to attain a particular dbh distribution. The exponential distribution may be useful for stands managed this way.

Projection of Stand Attributes

This last general area of research offers the greatest opportunity to pick and choose techniques and models of others. Because of the data limitations and the simplicity of the models, Moser and Hall's (1969) stand volume and basal area growth models were chosen for the first attempt. The only independent variables used are stand basal area and elapsed time. The basal area growth model is the generalized form of von Bertalanffy's growth-rate equation

$$dB/dt = nB^m - kB,$$

where:

dB/dt = periodic annual basal area growth (square feet per acre),

B = average basal area of pine 3.6 inches dbh and greater during the period, and n, m, and k are parameters.

The integral form is

$$B_t = \left[n/k - \left(n/k - B_0{}^{(1-m)}\right) e^{-(1-m)kt}\right]^{1/(1-m)}.$$

Stand volume is represented by the equation

$$V = b_0 B^{b_1},$$

where:

V = stand volume (cubic feet per acre, inside bark, of pines 3.6 inches dbh and greater from variable stump to a 3.5-inch top, inside bark);

B = basal area (square feet per acre); and

b_0, b_1 = parameters to be estimated.

Fitting the basal area growth equation resulted in

$$dB/dt = -.42457B^{1.0595} + .59116B,$$

and fitting the stand volume equation by nonlinear least squares yielded

$$V = 25.192B^{1.0209}.$$

The basal area growth equation coefficients are of the same relative magnitude and sign as Moser and Hall's (1969). The integral form of the basal area equation can be used to predict future stand basal area given initial basal area and elapsed time. Given present basal area and predicted future basal area, present and projected stand volumes can be calculated with the stand volume equation for the 90-ft site-index (loblolly, base age 50).

Most of the data had a range of 30-80 ft^2 in basal area. Basal area growth flattens perceptibly beginning at 60 ft^2 of basal area (fig. 1). The relationship of volume growth to basal area follows the same pattern as basal area growth (fig. 2).

These equations have enabled us to derive rough rules for growth and stand volume: (1) basal area growth of uneven-aged loblolly-shortleaf pine stands on site index 90 for loblolly will average about 3 ft^2 per acre per year, (2) annual volume growth is about 80 ft^3, and (3) these stands average about 27 ft^3 for every square foot of basal area. An average volume growth of 80 ft^3 agrees closely with the widely quoted average of 1 cord per acre per year for southern pines.

These two equations are the first effort in growth and yield, and research effort will be concentrated in this area. Work is progressing on development of a sawtimber volume yield model using these same data. Sawtimber volumes will be reported in board feet and cubic feet. This second development will still only be applicable to average sites and be based on local tree-volume functions.

Following completion of the sawtimber model, future models will be made more general by including other stand variables such as site quality. No measure of site quality has achieved the acceptance that site index has for even-aged forests. An adequate measure of site quality eventually must be found for uneven-aged loblolly-shortleaf pine stands. Since site index is such a widely used variable, an effort will be made to find out whether it might be used in somewhat altered form to estimate site quality in uneven-aged stands. A study is currently underway to test methods of soil-site evaluation for determining site index.

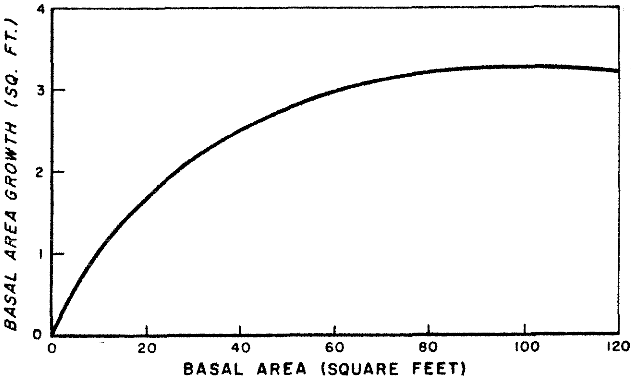

Figure 1.--Relationship of basal area growth to stand basal area for uneven-aged loblolly-shortleaf pine in south Arkansas

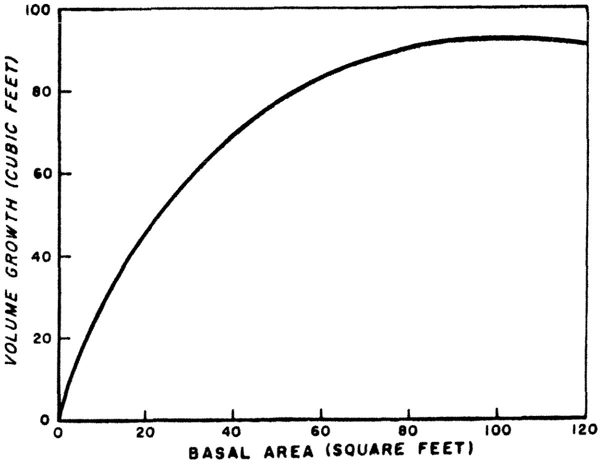

Figure 2.--Relationship of stand volume growth to stand basal area for uneven-aged loblolly-shortleaf pine in south Arkansas

Studies are continuing on stand structure. The next step in this area will be investigating other density functions like the Weibull. The truncated forms of distributions are particularly interesting, since stands are commonly regulated to a minimum merchantable dbh and maximum tree size. Limited experience with the exponential suggests that some gain in precision may result when the truncated forms are used. The exponential has not been discarded, because it may be useful for certain applications. Its efficacy for describing the diameter distributions of stands managed to a particular density, maximum dbh, and Q will be tested once data become available.

CONCLUSION

Efforts have been aided greatly by two factors. A broad charter has enabled researchers to look at the whole area of uneven-aged growth and yield for the loblolly-shortleaf pine type and to design a comprehensive, well integrated approach to problem solution. In the past, most uneven-aged work has been conducted in mixed species hardwoods, and the problem of species interaction has greatly complicated the problem. The task of modeling is greatly simplified by grouping loblolly and shortleaf pines together and initially ignoring the effects of hardwoods, which are usually burned or treated with herbicide periodically under pine management anyway. Benefit from these simplifications were sought, and the results so far have been encouraging.

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IMPACT OF PINE REGENERATION ON SOIL MICROORGANISMS[1/]

Shih-Chang Hu, J. M. Larkin and S. L. Edwards[2/]

Abstract.--Approximately 160 acres of mature loblolly pine were regenerated by the methods of clearcutting, seed-tree, shelterwood, and selection in southeastern Louisiana. Soil samples for microbiological examination were collected before and after the regeneration cuttings. Results showed that regeneration cuttings influenced the population of soil microorganisms.

INTRODUCTION

Soil fertility and productivity have been correlated with the abundance of microorganisms and their activities. The number of microorganisms varies with environmental factors such as oxygen supply, moisture content, temperature, acidity, organic matter, and season of the year. The practices of regeneration cuttings change the forest environment and hence may influence the population and activities of the soil microorganisms.

Niemala and Sundman (1970) reported that clearcutting of spruce in northern forest soils had caused a significant relative increase in caseolytic and lipolytic, rhamnose negative organisms, which also had a low acid tolerance. Cutting also increased bacteria of the genera Nitrosomonas and Nitrobacter 18-fold and 34-fold respectively (Smith et al. 1968). The population of soil microorganisms varies from one kind of forest to another. Chase and Baker (1954) compared microbial activity in Ontario forest soils under pine, hemlock and maple. Their results supported other workers' conclusions (Lutz and Chandler 1952, Russell 1950) that fungi predominate in coniferous forests. The fungi outnumbered the bacteria and actinomycetes combined.

Few studies of the microorganisms and their activities in the forest soils in the South have been done. The purposes of this study were to determine the numbers and types of soil microorganisms under a mature loblolly pine forest and to determine what changes may occur following regeneration cuttings.

METHODS AND PROCEDURES

Sampling Site

A study to determine the effects of pine regeneration on soil microorganisms was established in 1975. Approximately 160 acres of mature loblolly pine were regenerated by the methods of clearcutting, seed-tree, shelterwood and selection at Idlewild Experiment Station in southeastern Louisiana.

Five treatments and two replications were used. An undisturbed site in the same forest was chosen as a control. The control site was designated as site 1, the selection area as site 2, the shelterwood area as site 3, the clearcut area as site 4, and the seed-tree area as site 5. All sampling areas were in the middle of a square area approximately 40 m to a side within a 20-acre plot.

Sampling Procedure

Soil samples were collected from an area of approximately 10 cm^2 and from the top 3 cm as described by Larkin and Dunigan (1973), after brushing away the accumulated litter. Samples were placed in sterile whirl-pak plastic bags and immediately transported to the laboratory at ambient temperature, where each was homogenized by mixing and then analyzed.

An intensive microbiological examination was conducted with 4 precutting samplings obtained over a year to determine seasonal changes and to obtain baseline data. One sampling was done 3 weeks after cutting.

Laboratory Procedure

Soil samples were serially diluted and plated in triplicate to determine the populations of specific groups of microorganisms. For total aerobic bacterial populations peptonized milk agar (PMA) containing cycloheximide was used

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[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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(Larkin 1972). Actinomycetes and fungi were enumerated on Actinomycete agar and Sabouroud Dextrose agar respectively. Cellulolytic and proteolytic organisms were enumerated by detecting zones of clearing around colonies on PMA agar overlaid with a thin layer of 20% cellulose or 50% casein respectively. An aliquot of the diluted sample was heated for 10 min at 80°C and plated on nutrient agar to count sporeformers. Incubation of all plates was at room temperature and counts were recorded at 7 days (proteolytic organisms), 14 days (total bacteria, sporeformers, actinomycetes and fungi) or 21 days (cellulolytic organisms).

Approximately 100 organisms were isolated from each soil sample from the PMA plates. They were characterized with a battery of 22 biochemical tests using the BBL Minitek system. In addition, each isolate was examined by standard techniques for its ability to hydrolyze gelatin and casein, and to produce catalase and cytochrome oxidase. The Gram reaction, cell and colonial morphologies were examined on 18-hr cultures grown on nutrient agar. All of the features which were analyzed are shown in Table 2.

Factor Analysis of Results

The characteristics of each isolate were encoded binomially for statistical evaluation. The correlations between each pair of n tests were calculated for all isolates, and the n x n correlation matrix was condensed by factor analysis to a J-dimensional factor space (Sundman, 1968). The factorization was carried out as a principal axis factor solution using maximum correlation of each variable as the estimate of communality.

Factors were extracted and subjected to between/within population analysis of variance to determine their discriminative powers. Factors which gave between/within ratios of $p \geq 0.05$ were excluded as non discriminative (Sundman 1970).

RESULTS AND DISCUSSION

The numbers of total aerobic bacteria, proteolytic organisms, fungi, sporeformers, actinomycetes, and cellulolytic organisms from each sampling date are listed in Table 1.

Total Aerobic Bacteria Count

The number of total aerobic bacteria fluctuated among sampling dates. Following the regeneration cutting, the count in the control site decreased about 10 fold from the previous count. A decrease in about the same amount was also found in other sites. Thus, the decrease in total count may be due to seasonal change rather than regeneration cuttings.

The numbers of total aerobic bacteria at all sites ranged from 10^6 to 10^7/g dry wt. of soil. Other workers (Rybalkina 1957, Stout 1961, Terehov and Enikeeva 1964, Berry 1967) have found that total aerobic bacteria in coniferous forests ranged from 10^5 to 10^6/g dry wt. The bacteria were most numerous in April and least numerous in July. Fungi were most numerous in July and least numerous in April. This pattern was also observed by Wright and Bollen (1961) whose studies of a douglas fir forest indicated that when bacteria were most abundant fungi were least numerous and vice versa.

Proteolytic Organisms

The proteolytic bacteria showed a relationship with the seasons. The counts were generally higher in the summer and fall than in the winter and spring. The populations of the proteolytic organisms increased after regeneration cuttings.

Fungi

The numbers of fungi fluctuated at the various sampling dates with no obvious relationship to seasons. The predominant genera seen were Penicillium spp., Aspergillus spp., Alternaria spp., and Rhizopus spp. In three of the four samples obtained before cutting, the bacteria outnumbered the fungi by levels of 2 to 10 fold. After cutting, the fungi outnumbered the bacteria by 2 to 3 fold. Thus, the cutting raised the fungal population. It rained for an extensive period of time before the last sample was collected and this could have contributed to the increased number of fungi. Warcup (1957) reported that fungi increase in numbers after heavy rainfall. Other workers (Chase and Baker 1954, Lutz and Chandler 1952, Russell 1950) have found that the fungi predominate in coniferous forests and that fungi usually outnumber bacteria and actinomycetes combined. Terehov and Enikeeva (1964), however, found that mean counts of bacteria outnumbered combined counts of fungi and actinomycetes by 3 fold.

Sporeformers

The counts of the total sporeforming bacteria fluctuated among the sampling dates, but they did not seem to correlate with specific seasons. However, in all samples obtained after cutting they were at their lowest levels. The decrease following the cutting cannot be attributed to the cutting because the control site also decreased to its lowest level.

Before cutting, the sporeformers accounted for approximately 15-30% of the total bacterial population. After cutting they accounted for 5-10% of the bacterial population. The level of sporeformers decreased more rapidly after cutting than did the bacterial population as a whole.

Table 1.--The counts of various classes of microorganisms at Idlewild Experiment Station (forest 1) at various times before and after cutting

Sample	February[1] 14, 1976	July 7, 1976	October 16, 1976	April 20, 1977	December 14, 1977
Total aerobic bacteria					
Control site	3450[2]	280	5860	4080	410
Site 2	5020	3840	2830	3810	400
Site 3	3200	4550	1110	6400	410
Site 4	1700	1230	2910	11500	2040
Site 5	3780	2550	12000	3020	570
Mean of 2-5	3425	3043	4712	6182	855
Proteolytic organisms					
Control	120	1380	2200	100	100
Site 2	870	12000	760	410	1880
Site 3	260	1460	360	100	420
Site 4	250	1340	4500	230	710
Site 5	530	6100	10700	230	1260
Mean of 2-5	420	5225	4080	242	1067
Fungi					
Control	1100	280	590	440	460
Site 2	520	11800	1000	400	2210
Site 3	650	1030	530	830	1260
Site 4	840	1690	1140	710	1670
Site 5	630	1760	880	260	1080
Mean of 2-5	660	4510	888	550	1555
Sporeformers					
Control	520	430	520	130	22
Site 2	880	410	340	490	32
Site 3	380	1840	890	290	18
Site 4	370	370	2300	2400	90
Site 5	420	2350	380	2000	71
Mean of 2-5	513	1160	978	1295	53
Actinomycetes					
Control	1360	30	3940	530	1800
Site 2	1680	4310	2790	1960	60
Site 3	500	480	470	3020	30
Site 4	820	400	1820	550	460
Site 5	950	1780	5760	1690	80
Mean of 2-5	988	1743	2710	1515	158
Cellulolytic organisms					
Control	2.9	2.2	2.7	2.4	2.5
Site 2	5.8	4.8	3.1	2.7	2.9
Site 3	3.5	3.4	2.9	3.1	2.8
Site 4	8.4	7.1	7.5	7.8	4.3
Site 5	3.3	2.9	2.9	1.4	3.1
Mean of 2-5	5.2	4.6	4.1	3.8	3.9

[1] February, July, October and April are precutting sampling dates; December is the sample taken three weeks after cutting.

[2] Counts x 10^4/gram dry weight.

Actinomycetes

The level of actinomycetes fluctuated in a way that could not be directly related to changing seasons. After cutting, the experimental sites contained only 3-5% of the actinomycetes that were found in the control sites. Regeneration cuttings decreased the population of the actinomycetes. In all cases before cutting the numbers of actinomycetes were equal to about 25-50%

Table 2.--Extract of principal axes matrix of Idlewild Experiment Station. First two estimates of loadings ≥ 0.30 are given. Plus signs are omitted.

Character	Factor I	II	III	IV	V
Cells spherical				-0.35	
Rods axis straight				0.39	
Rod w pointed ends					
Flexuous rods					
Endospores present		0.71			
Endospores spherical					
Endospores central to subterminal		0.66			0.31
Sporangium swollen		0.42			0.33
Capsule					
Gram + or variable					
Cells: singly					
pairs					
irregular clusters		-0.40			
chains		0.46			
packets					
palisades					
rosettes					
Colony pigmented			-0.31	0.62	0.55
Carotenoid pigments			-0.31	0.62	0.55
Fermentation of a pentose	0.38		0.68	0.31	
Fermentation of xylose	0.56				
Fermentation of arabinose	0.34		0.70	0.32	
Fermentation of rhamnose	0.42				
Fermentation of hexose	0.70		0.33		
Fermentation of fructose	0.66			0.37	
Fermentation of glucose	0.69				
Fermentation of salicin	0.60				
Fermentation of a disaccharide	0.70				
Fermentation of sucrose	0.65				
Fermentation of lactose	0.57				0.32
Fermentation of raffinose	0.47				
Fermentation of starch					
Arginine decarboxylase			-0.30		-0.35
Phenylalanine deaminase					
Malonate utilization					-0.34
Citrate utilization	0.31				-0.36
Acid from glucose aerobically	0.48				
Nitrate reduction	0.32				
H_2S production					
Indole production					
Urease production					
Casein digestion		0.46			
Gelatin hydrolysis		0.46			
Catalase production					
Cytochrome oxidase		0.32			
Mannitol utilization	0.48				
Gylcerol utilization	0.50				
Vogues-Proskauer					
Factor variances:	7.12	6.78	10.04	8.02	4.99
% of total :	19.20	18.30	27.20	21.70	13.50

of the total bacterial count. After cutting this population dropped to about 10-15% of the total bacterial population.

Actinomycetes numbered in the range from 10^6 to 10^7/g dry wt. of soil and were most numerous in October. Rybalkina (1957) found actinomycetes present at lower numbers and they were most numerous in October. Terekhov and Enikeeva (1964) reported forest soil populations in which the actinomycetes numbered 10^5/g dry wt.

Cellulolytic Organisms

The populations of cellulolytic organisms remained relatively constant at each site throughout the experimental period and were approximately 1-2% of the total bacterial population. After cutting, there was no significant change in the populations.

Factor Analysis

From an analysis of each of the bacterial isolates, five factors were extracted. The factors are shown in Table 2. Factor I was primarily a carbohydrate fermentation factor. Factor II was a Bacillus (sporeformer) factor. Factor III was a nonpigmented, arabinose and fructose fermenting group. Factor IV was dominated by carotenoid pigment containing rods of the Flavobacterium-Cytophaga group. Factor V also contained carotenoid-pigmented organisms but also included spores and is thus interpreted as a pigmented sporeformer group.

Although the relative input of the factors into the total microbial picture changed with the seasons, only factors II and V followed a discernible pattern. Factor V (pigmented sporeformers) had its maximum input during the summer and its minimum input during the winter. Factor II (Bacillus) showed the opposite response. This may be due to increased sunlight in the summer, as discussed below.

Two important features appeared as a result of the factor analysis. First, after harvesting the trees the importance of the nonpigmented sporeformers (II) and the carbohydrate fermenters (I) decreased while the two factors (IV and V) which contain the carotenoid pigmented groups increased in importance. This very likely is due to selective pressure on the microbial populations brought about by the increased amount of sunlight hitting the forest floor after harvest. Carotenoid pigments protect bacteria from photooxidation (Liaaen-Jensen 1965) and bacteria which produce them had a selective advantage when the forest floor suddenly received an increase in sunlight.

Second, before harvesting the trees in the experimental sites the factor analyses showed that the relative importance of each factor varied from site to site. This indicated that the sites themselves were not identical even though they were selected on the basis of their overall similarity in slope, overhead cover, etc. After harvesting, the inputs of the various factors from all experimental sites came closer together when compared with their spread at previous times. Thus, the vegetation cuttings converted four sites with dissimilar microbial populations into four very similar sites. This may be due to two factors. The removal of all or most of the trees would make the sites more alike by equilibrating their exposure to sunlight, wind, rainfall, etc., and secondly, the disruptive effects on the soil by the logging crews and equipment would tend to reduce the differences among the sites.

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A COMPARISON OF CATION SAMPLING IN FOREST SOILS BY TENSION AND TENSION-FREE LYSIMETERS[1]

James H. Miller[2]

Abstract.--Field tests conducted in two soils with ceramic cup, ceramic plate, and tension-free lysimeters showed no concentration differences in collected cations (Ca, Mg, K, Na) between cups and plates, except for the hydrogen ion. Mean pH was 0.6 lower in cup collected samples for a sandy loam profile. Tension-free lysimeters of the design tested had persistent contamination from a glasswool component and yielded samples at a 60 cm depth from a clay loam profile and not from a loamy sand soil. Laboratory trails showed a marked response delay with plate lysimeters when sampling changing cation concentrations.

INTRODUCTION

Tension and tension-free lysimeters are being used more often to monitor natural processes in soil profiles and nutrient-loss impacts after cultural treatments. These devices permit solution sampling within and beneath undisturbed soil profiles. This cannot be done yet by other means. Tension lysimeters with porous ceramic cups have been used to monitor environmental contaminants (Parizek and Lane 1970, Nutter et al. 1978, Neary et al. 1979) and nutrient leaching processes (Vitousek et al. 1979, McColl 1978, Gosz and Dyck 1979). Tension plate techniques developed by Cole (1968) have clarified leaching mechanisms (McColl and Cole 1968) and nutrient losses following forest practices (Gessel and Cole 1965, Grier and Cole 1971). Jordon (1968) refined techniques using tension-free lysimeters and employed these to investigate nutrient transfers in tropical forest ecosystems (Kline and Jordon 1968; Stark and Jordon 1978). The investigative potential of such sampling devices is great, but the validity of cation sampling by the different lysimeters has not been fully explored.

The objective of this study was to compare tension-cup, tension-plate, and tension-free lysimeters for quantifying nutrient losses from forest lands after vegetation management treatments. Each device was tested in the laboratory for response variation while sampling known concentrations of cations. A field study tested differences in concentrations from devices placed in isolated profiles with vegetation uptake eliminated. Sampling bias with the ceramic cup has already been shown for phosphate (Hansen and Harris 1975) and ammonium (Wagner 1962) which were not studied further here.

MATERIALS AND METHODS

Ceramic cup and plate samplers used in this investigation are the commercial models manufactured by Soil Moisture Equipment Corp., Santa Barbara, California.[3] The ceramic cup has a 2-bar bubbling pressure (or air entry value) with an outside diameter of 49.5 mm, an exposed length of 61 mm and ceramic thickness of 2 to 3 mm. Specified lengths of polyvinyl chloride (PVC) pipe are cemented to the cup permitting greater sampling depth and differing ratios of sample volume to vacuum-reservoir. The 60 cm length of PVC was tested here.

Plates are constructed of 0.5 bar ceramic with variable diameters of 265 to 275 mm and a thickness of 9 mm. A rubber disk with outport is attached to one side of the ceramic plate by peripheral wire and cement with a screen

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[3] Use of trade, firm or corporation names in this publication is for the information and convenience of the reader. Such use is not an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

interlayer to permit water flow. Connection between outport and a combination vacuum-sample bottle is by vacuum hose and copper tubing. Solutions collected with the plate must travel through 3 to 4 times more ceramic material than with the cup samplers, which have absorptive properties.

Ceramic cups are made from a non-vitreous porcelain which contains more or less equal proportions of kaolin, alumina (Al_2O_3), ball clay, and other feldspathic materials.[3] The Al_2O_3 is essentially pure and 30% of the kaolin and ball clay are composed of this compound. Plates are 90% Al_2O_3, 6% kaolin and 4% ball clay. Kaolin and ball clay in both lysimeters are over 50% by weight SiO_2 and have potential contaminants of iron, calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), and titanium in amounts less than 1.5% each. Initial treatments of ceramic samplers are used to reduce the leachable or exchangeable cation contaminants (Gover and Lamborn 1970, Wolff 1967). I washed all ceramic samplers first with distilled water (DW) to remove ceramic dust, then 300 ml of 1N HCl was drawn through each, and finally, 1.2 liters of DW was tensioned through each lysimeter. This volume of DW was required before cation contamination reached zero.

Tension-free lysimeters were constructed of a 285 mm diameter funnel made by cutting off the upper portion of a 20-liter plastic carboy at the shoulder and inverting it on the bottom as a base. A drilled hole in the carboy cap with an epoxied connector served as an outport permitting tubing to be attached to a sample bottle. Glasswool filled the funnel and facilitated water flow (Stark and Jordon 1978). Repeated acid treatment (2% HCl) and DW washes of laboratory-grade glasswool was unsuccessful in eliminating cation contaminants. Average contaminant concentrations in a 300 ml DW wash were Ca 0.9 mg/l, Mg 0.5, K 0.2, and Na 2.0. Polyester fiber was also substituted for the glasswool and yielded similar contaminant concentrations. Due to this problem, tension-free data will be presented separately in the laboratory and field results.

In the laboratory trails, 300 ml aliquots of a premixed solution of four cations were sequentially drawn (0.4 bar tension) or passed (tension-free) through the samplers and analyzed using standard atomic absorption techniques. The solution concentrations were Ca 0.85 mg/l, Mg 0.45, K 0.23 and Na 3.10. Finally a 300 ml DW was then drawn or passed through each and analyzed. This procedure was repeated on three devices of each type to test the responsive capabilities of the samplers.

In field comparisons, three lysimeters of each type were installed in a randomized complete-block design with three blocks in a loamy sand and three in a clay loam soil. The two installations are about 150 m apart and both are located in natural clearings under 53-year-old plantations of loblolly (Pinus taeda) and shortleaf pine (P. echinata). An access trench 1.5 m wide, 3 m long, and 1.5 m deep in the clearing centers was provided with a wooden shelter, with open sides for profile access. A sloping roof drained away from the installations. Tension plates and tension-free samplere were installed laterally in the trench walls. Cups were installed by auger holes using a 200-mesh silica sand interfacing material at the bottom of the hole. Lysimeters were emplaced at a 60 cm depth on the loamy sand site and at 45 cm on the clay loam site, below lateral rooting of the pines and equidistant from the access trench. A 30 cm wide and 1.5 m deep root exclusion trench surrounded the installation at a distance of 1.5 m from the access trench. Polythene sheeting was backfilled to the inside walls of the trenches to prevent root encroachment. All vegetation within each installation was carefully cleared and kept clear for the duration of the study. Thus plant uptake was eliminated as a variable.

A vacuum of 0.3 bars was maintained on tension devices over a collection period only during times of adequate soil moisture. At low soil moisture, cups maintained tensions more consistently than the plates, which required reevacuation periodically. Although cups maintained vacuum at lower soil moisture than plates, very little sample was collected during these periods. Tension-free lysimeters collected samples only after intense storm events.

Soil solution was collected 3 days after storm events or biweekly during extended rainy periods. Analyses included specific conductance Ca, Mg, K, Na, and pH. Specific conductance was measured with a conductivity meter with samples placed in a 25°C bath. Cations were determined by atomic absorption spectrophotometry. The pH was measured potentimetrically.

RESULTS AND DISCUSSION

It is commonly thought that ceramic samplers reach equilibrium with the soil solution after installation. Thus, the process of adsorption, diffusion, and screening which biased phosphate sampling (Hansen and Harris 1975) merely delay the actual changes in soil solution concentrations when monitoring a profile. This detection delay can readily be seen in the laboratory results with the plate samplers (Fig. 1). With Ca, 1.5 liters of a 0.85 mg/l solution were drawn through the plates before the premixed sample concentrations were approached. Other cations reached equilibrium within 600 ml.

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[3] Personal communications with Mr. P. E. Skaling, Soil Moisture Equipment Corp.

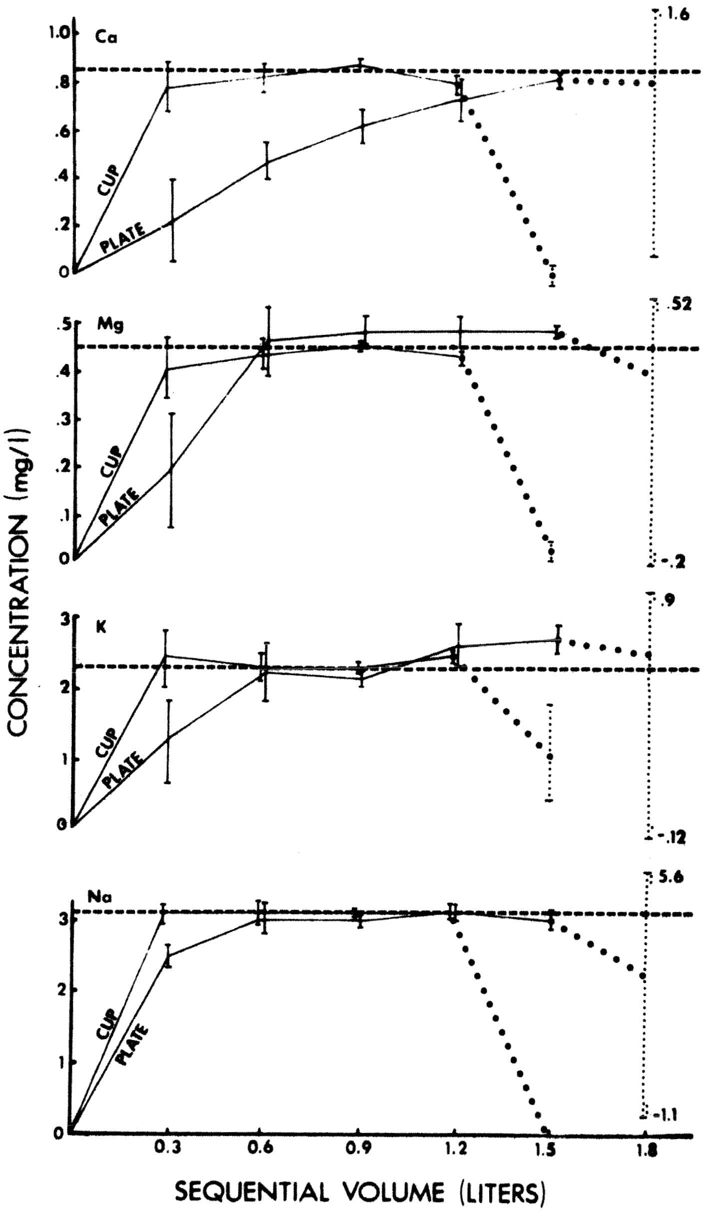

Figure 1. Mean concentrations of samples drawn from a known solution (concentrations indicated by horizontal dashed lines) and the sample standard deviations (vertical lines). The dotted lines indicate a final distilled water wash (0.3 liters) and the subsequent wash concentration.

Concentrations higher than the test solutions were found in samples for Mg and K. This phenomenon and the variable concentrations in the DW, evident by the large standard deviations, must result from desorption of bound ions. The large standard deviation also shows this desorption response to vary greatly from plate to plate. The plate with the slowest concentration response had the slowest average flow rate.

No percolating water reached the tension-free sample containers at the sandy site.

Using sample concentrations from the 12 storms as observations, a two-factor analysis of variance tested differences (1%) between soils and between cup and plate lysimeters. An additional analysis of variance and Duncan's multilpe range tests were performed on the three lysimeter types using the tension-free collections in the clay loam soil.

Table 1. Mean cation concentration in solution washes of known concentration and a final wash of DW through tension-free lysimeters.

Solution	Ca	Mg	K	Na
	mg/l			
Premixed Concentration	0.85	0.45	0.23	3.1
1	7.52	1.05	.72	15.8
2	3.44	1.83	.67	15.1
3	2.21	1.09	.38	7.4
4	1.60	.80	.26	4.8
5	1.42	.71	.23	4.2
DW wash	2.82	1.32	.73	8.1

Cup lysimeters showed a more rapid response to drastic concentration changes. Although deviations from test resolution concentrations of ± 1% are apparent, the accuracy of analysis approximates ± 1% at these concentrations. Potassium desorption or leaching in the DW wash of cups points to a source of sampling bias with decreasing concentrations.

Persistent contamination was in the solution washes and DW washes passed through the tension-free devices (Table 1). Sodium was most concentrated. These devices had been previously washed with over 20 liters of DW in an attempt to eliminate the glasswool contaminants. The premixed concentration of K was finally reached after 1.5 liters, but absorbed or bound ions of all cations were leached in the DW wash.

Twelve storm periods were sampled at the field sites between July and November 1979. The longest storm was two weeks and the shortest 3 days. All devices had been previously installed and samples collected for at least 2 months before the July sampling commenced. This waiting period allowed for ample equilibration time. If equilibration of the ceramics does take place, then solution concentrations collected from both devices in the uniformized soil profiles should be the same. Collection from tension-free lysimeters were only made at the clay site during the sampling period.

Mean values for the 12 collections presented in Table 2, show no significant differences (1% level) between cups and plates for specific conductance, and Ca, Mg, K, and Na concentrations. The two samplers in loamy sand and clay loam soils, showed that total ionic concentrations were less in the clay soils as evident by significantly lower mean specific conductance. Significantly lower Ca concentrations appear responsible for the lower specific conductance in the clay profile. Two of the plate lysimeters in the sandy profile consistently gave higher concentrations for Mg and Na and corresponingly lower values for Ca and K. This appears to be endemic profile variation and was not found to be significantly different. Thus, monitoring of the most concentrated cations does not differ between lysimeter types at the concentration levels tested with an *in vivo* situation.

The only significant difference was pH. Plate lysimeters consistently collected samples that were .2 to .6 pH units higher. Due to the logarithmic nature of the pH scale, hydrogen ion activity was 1.5 to 4 times greater with the cup samplers. It would appear that selective absorption or screening or hydrogen ions was occurring with the plates and an equilibrium between the soil solution, ceramic plate, and sample solution had not been reached.

Sample contamination is evident in the mean concentrations from tension-free devices presented in Table 2. Magnesium concentrations were the only cations sampled that were not different from cup and plate samples. The inability to sample below rooting-zone depths in loamy sand soils plus the contamination problems with the glasswool polyester fiber will preclude the use of this sampler type in future forest nutrient-loss research.

Table 2. Specific conductance, pH, and cation concentrations collected from two soils using three lysimeter types.

Soil	Lysimeter	Spec. Cond.	Ca	Mg	K	Na	pH
		µmhos/cm	--------	--------	mg/l	--------	--------
Loamy Sand	Cup	102a[1]	5.8a	2.1a	0.9a	1.6a	5.8a
	Plate	117a	4.1a	3.4a	.4a	1.9a	6.4b
Clay Loam	Cup	60b	1.0b	2.0a	.9a	1.5a	5.9a
	Plate	65b	1.0b	1.9a	1.1a	1.4a	6.1b
	Tension-free[2]	200c	4.1c	2.7a	2.3b	24.3b	7.5c

[1] Means in a column followed by the same letter are not significantly different at the 1% level.

[2] Tension-free data compared to the cup and plate collections in the clay loam soils only.

CONCLUSIONS

The cup lysimeter is the most reliable device for sampling cations, although a bias in phosphate and ammonium sampling has been demonstrated for these samplers (Hansen and Harris 1975; Wagner 1962). If the type of plate lysimeter studied in this investigation is used, then initial samples may not reflect actual soil solution concentrations due to plate adsorption. Plate-collected samples will not reflect accurate concentrations when drastic seasonal changes in soil solution concentrations occur. Cups are easier to install but plates have the distinct advantage of quantifying nutrient loss on an area basis due to the flat shape. The use of both cups and plates is needed to accurately sample cations and given an areal-loss estimate.

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SOILS INTERPRETATIONS FOR SILVICULTURE IN THE SOUTHEASTERN COASTAL PLAIN[1]

R. F. Fisher[2]

Abstract.--Successful intensive silviculture must manage the soil resource wisely. Toward this end, CRIFF has developed a system of soil groups and silvicultural interpretations to be used in pine management in the coastal plain. These are "state of the art" interpretations and are, of course, subject to change as our knowledge increases.

INTRODUCTION

Productivity is an elusive concept. Although the dictionary is straight forward in its definition of the term, the application of the concept to natural resources has taken many forms, and as often as not discussions concerning the maintenance of site productivity never get beyond the definition of terms. The purpose of this paper is to suggest ways of maintaining and enhancing site productivity. I will not even attempt to define productivity. Rather I shall assume that production of wood, water, wildlife, range, and recreation is maximized when the soil resource on any given site is in the best possible condition.

Best possible condition does not mean a deep, friable, silt loam high in organic matter on every site. It simply refers to the best physical, chemical, and biological conditions that can be expected given the parent material, topographic position, and climate of the site. Thus any operation or treatment that degrades the soil's physical, chemical or biological condition would be deemed detrimental to the maintenance of productivity, and any activity that more or less permanently improves the soil's physical, chemical or biological condition would be considered as enhancing productivity.

One might argue that if we cannot define productivity we cannot measure it, and if we cannot measure it we cannot determine whether or not an activity significantly reduces or enhances productivity. This is true; therefore, we often use easily obtained measures such as cubic feet of wood grown per acre per year to judge the good or ill of management activities. Herein lies a great pitfall. Since we do not possess simple, direct and universally accepted measures of productivity for resources such as water, wildlife, and recreation we often stamp an activity as beneficial and desirable when in fact it degrades the soil and the production of one or more of these imprecisely quantified resources. This is why I have chosen to use soil condition as the key to site productivity even though the analysis of economic returns on the maintenance and enhancement of soil condition is nearly impossible.

Soil Groups

This guide is based on a simple soil group system (Table 1). The soil groups are defined on the basis of drainage class, depth to and nature of the B horizon and the character of the A horizon. The information necessary to place a site into a soil group can easily be obtained in the field or from existing soil survey maps.

These soil groups are intentionally broad. Extremely detailed classification systems lead to many small subdivisions that in practice are too small to treat separately. This soil grouping system usually does not produce an overabundance of small units, yet the system, where

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it has been applied in the coastal plain, has produced units that are uniform in response to silvicultural treatments (Fisher and Garbett, 1980; Kushla and Fisher, 1980). In other words these soil groups appear to be broad enough to be usable but accurate enough to be useful.

Species Selection

The simplest way to increase productivity is to grow the proper species of tree on each site. This is not only true when timber is the resource in question, but it is also true when other resources are considered. For every site, there are one or more tree species that are best at producing timber, wildlife habitat, water yield, etc. Unfortunately a single species or small group of species seldom maximizes the

Table 1.--CRIFF soil group definitions.

Soil Group	Drainage Class	Diagnostic Horizon	Subgroup Equivalents	Representative Series
A	Very poorly to somewhat poorly drained	No spodic horizon; argillic within 20 in.	Typic & Plinthic Aquults	Portsmouth-Bladen
B	Very poorly to somewhat poorly drained	No spodic horizon; argillic below 20 in.	Arenic & Grossarenic Aquults, Aquents & Aquepts	Rutledge-Plummer
C	Very poorly to somewhat poorly drained	Spodic & argillic horizons present	Ultic Aquods & Humods	Mascotte-Sapelo
D	Poorly to moderately well drained	Spodic but no argillic horizon present	Typic, Aeric, & Arenic Aquods & Humods	Ridgeland-Leon
E	Moderately well to well drained	No spodic horizon; argillic within 20 in.	Typic & Plinthic Udults	Goldsboro-Norfolk
F	Moderately well to well drained	No spodic horizon; argillic below 20 in.	Arenic & Grossarenic Udults, Umbrepts & Ochrepts	Blanton-Orsino
G	Somewhat excessively to excessively drained	No spodic horizon; argillic may or may not be present	Psamments	Lakeland-Eustis
H	Very poorly to poorly drained	Organic surface > 20 in. thick	Medisaprists & Histic Humaquepts	Kingsland-Pettigrew

production of all resources. Most often species are selected which will maximize timber production.

In the coastal plain, pines are the preferred species for reforestation. The establishment of large areas of pine plantations in this region is not as detrimental to other resource values as might be expected. This is due to the relative ease with which pines can be established in the coastal plain, and to the large area of land in ponds, drains, etc., which is not converted to plantations.

Table 2.--Recommended species by soil group.

Soil Category	Species in Order of Preference
A	loblolly[1], slash, hardwood
B	slash, loblolly[1], hardwood
C	loblolly[1], slash, longleaf[2]
D	slash, loblolly[1], longleaf[2]
E	loblolly, slash, longleaf
F	slash, loblolly, longleaf
G	longleaf or sand
H	loblolly[1], slash

[1] Loblolly should be used only if adequate phosphorus is supplied.

[2] Longleaf should be used only on better drained soils in the group.

The guide given in Table 2 is very general and should be augmented with local knowledge as to species suitability. Loblolly pine is preferable over slash in soil groups A and C only if phosphorus (P) is applied at time of planting and in areas where the tip moth problem is not severe. Longleaf pine grows well on soil groups C and D sites that are better drained than the average for those groups. Likewise it does well only on the better soil group G sites.

There have been many species comparison tests carried out in the past and the results are quite confusing. Most of these tests were not adequately fertilized nor were the most suitable seed sources always planted. The recommendations in Table 2 are based on the use of the most adaptable seed source, high quality nursery stock, and proper fertilizer treatment.

Harvesting

A major cause of losses in site productivity is soil damage during harvest. This may be hard to believe since the avoidance of such damage appears simple; however, difficulty in managing the cutting operation leads to losses of top soil on thousands of acres each year.

Table 3 presents some limitations for harvest cutting by soil group. In soil groups A and B wet weather logging can cause compaction and surface disturbance which leads to large top soil losses. Staying off these sites during wet weather makes good sense both from a soil management standpoint and from an ease of logging standpoint, but this goal seems hard to reach.

Table 3.--Limitations for harvest cutting by soil group.

Soil Group	Limitation
A	Do not log in wet season.
B	Do not log in wet season.
C	Full tree harvest may reduce residual fertility.
D	Full tree harvest may reduce residual fertility.
E	Do not log in wet season.
F	Few limitations.
G	Few limitations.
H	Choose equipment carefully.

The spodosol soil groups, C and D, are low in organic matter and harvest systems which remove large amounts of debris from the site may seriously lower soil organic matter. Such damage is often not reflected in timber yields, but severely damages understory productivity, browse and forage quality, and increases sediment loss into neighboring streams. Harvest systems that leave logging slash equitability distributed over the site are to be preferred on these soil groups.

The fine textured surface soil in soil group E can easily be compacted if these sites are logged in wet weather. This will reduce yield or lengthen rotation age in the subsequent stand, and can often lead to surface soil loss and increased sedimentation. Although F group soils have more friable surfaces they can also produce a good deal of sediment if sloping soils are badly disturbed.

The H group soils are difficult to log at best. The choice of the proper equipment and operation in the driest season will hold damage to these sites to a minimum. I realize that the foregoing seems oversimplified, and that foresters complain they have no time to oversee nor no power to control logging contractors, but this is an area where we can and must apply better management.

Water Control

Water control or drainage (Table 4) is an important way to improve productivity on many coastal plain sites. Access drainage for road building and harvest activities consists of the construction of roads and their ancillary ditches through low, wet areas. This activity, when improperly carried out, may lead to extensive destruction of terrestrial and aquatic habitat. Such work has all but been stopped by recent legislation and public pressure. This means that large areas in soil groups A, B, C, and H will never be highly productive of timber, range and certain wildlife species.

Table 4.--Water control needs by drainage class within soil groups.[1]

Soil Category	DC[2]	Access Drainage	Silvicultural Drainage
A	0-1	necessary	necessary
	2	necessary	necessary until age 5-10
B	0-1	necessary	necessary until age 5-10
	2	beneficial	beneficial until age 5-10
C	0-1	necessary	necessary until age 5-10
	2	unnecessary	unnecessary
D	0	beneficial	beneficial until age 5-10
	1-2	unnecessary	unnecessary
E,F & G		unnecessary	unnecessary
H	0-1	necessary	necessary

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[1] Access drainage consists of major ditch networks necessary to lower the water table over large areas. Silvicultural drainage refers to secondary ditch systems intended to lower the water table temporarily over short distances, and bedding or mounding to given new seedlings drainage within the root zone.

[2] DC = drainage class.

In these soil groups, areas that have already been drained can remain productive, with little further environmental degradation, if they are wisely managed. Well regulated water control structures in access drainage systems can moderate high and low flows and reduce siltation from new silvicultural activities.

Silvicultural drainage means small, short term lowering of the watertable to help seedlings become established. Once the trees are established they will transpire enough water to lower the watertable and drainage will be unnecessary. For this reason, interbed trenches or small lateral ditches put in to provide silvicultural drainage should be closed up after 5 to 10 years when the stand of trees begins to control the watertable.

Experiment evidence for the value of such drainage has been contradictory; however, care should be taken in interpreting these results. Often control plots eventually begin to benefit from the drying of the site produced by the treated areas and differences between treated and control areas subside. This delayed response of control areas might never have occurred if it were not for the presence of the treated areas in the same vicinity.

Fertilization with phosphorus can substitute for drainage on some not-so-wet sites but not on all sites. On most wet sites the response to drainage and fertilization with P is more than additive (Tables 5 and 6).

Table 5.--Response of young pine to fertilization and site preparation on coastal savanna sites (Soil groups A and B).

Fertilization	Site Preparation None	 Disc	 Bed
	------ft^3/A at age 8---		
None	30	80	130
Concentrated superphosphate	90	185	450
diammonium phosphate	120	220	380

Site Preparation

Site preparation is both a great boon and a great bane to productivity. When it is properly done, site preparation creates favorable soil physical and chemical conditions and reduces competition, thus speeding early growth and decreasing the rotation age. When improperly applied, site preparation creates poor soil physical and chemical conditions and reduces growth, while also reducing forage production, causing a loss of

Table 6.--Response of young pine to fertilization and site preparation on flatwoods sites (Soil groups C & D).

Fertilization	Site Preparation None	 Disc	 Bed
	-----ft^3/A at age 8-----		
None	125	160	205
Concentrated superphosphate	135	190	265
diammonium phosphate	185	235	310

wildlife habitat, lessening watershed quality and making the site look horrible. This dicotomy argues strongly for careful application of site preparation treatments.

Foresters have become enamored with machinery and with pine trees; these two facts alone have lead to most of the problems in site preparation. Bigger tractors and cleaner sites are not necessarily better, and overzealous preparation to control hardwoods so that pine can be established generally leads to site deterioration and losses in resource values, even pine production itself.

The treatments recommended in Table 7 are calculated to adequately prepare the site while conserving soil organic matter and fertility and minimizing soil erosion. Such treatment should be beneficial to all resource values save for the temporary loss in visual quality. If the recommended treatment is not adequate to allow for the establishment of pine on some sites, then those sites can not be expected to support pine without the loss of other resource values.

Treatments in the table are in order of preference. The availability of equipment or contractors may dictate some modification in these recommendations. However caution must be taken not to use such factors as excuses for not applying the proper site preparation methods.

Fertilization

The fertilizer recommendations in Table 8 are primarily based on the results of experiments which monitored tree growth and yield. However these treatments should be beneficial to a variety of resources. Limited data from the University of Florida's Cooperative Research In Forest Fertilization Program (CRIFF) files shows a significant improvement in forage and browse on soil group A and C sites fertilized as recommended in Table 6. Watershed and recreational values should also profit from the better soil and vegetation conditions brought about by these treatments. CRIFF experience shows that little fertilizer, aside from that actually applied to water in ditches, streams, etc., ever reaches the runoff water in most fertilized forests. This is due in part to rapid uptake by the vegetation and in part to the fixation of many fertilizer elements in the soil.

Table 7.--Site preparation and regeneration recommendations for pines by soil group.

Soil Group	Preparation
A	chop, burn, chop, double bed, plant chop, burn, disc, bed, plant
B	chop or double chop, double bed, plant chop, burn, disc, bed, plant
C	chop, disc, bed, plant chop, burn, bed, plant
D	chop, bed, plant chop, disc, bed,plant
E	chop, plant chop, burn, plant
F	chop, plant plant in rough
G	chop, plant or seed natural regeneration
H	chop, plant or seed chop, burn, plant or seed

More complex and sophisticated fertilizer formulations than those in Table 8 may be used; however there is little data, as of now, to show that these are more effective than those recommended here.

As can be seen from the probability of response column, not all sites in most soil groups respond to fertilization. Simple soil tests or more complex regression equations developed by Kushla and Fisher (1980) may be used as further checks on the probability of response on a given site.

Soil Test Values Indicative of Responsive Sites

Element	Double Acid Extractable Amount (lbs/A)
Phosphorus	< 8
Potassium	< 20

Table 8.--Recommendations for fertilization at time of planting.

Soil Group	Treatment	Probability[1] of Response	Volume Gain[1] $ft^3 A^{-1} Yr^{-1}$
A	50 lbs P/A as GRP[5]	100%	+50 to +75
B	50 lbs P/A as GRP, CSP, or DAP[2]	90%	+20 to +40
C	50 lbs P/A as GRP, CSP, or DAP[2]	75%	+15 to +30
D	50 lbs P/A as GRP[2]	75%	-5 to +15
E	50 lbs P/A as DAP	25%	-5 to +15
F	50 lbs P/A as DAP[3]	50%	-5 to +50
G	50 lbs P/A as DAP[4]	50%	-5 to +5
H	50 lbs P/A as GRP or CSP	75%	-5 to +30

[1] Estimated from over 40 CRIFF trials with slash, loblolly, and sand pine.

[2] These sites may benefit from the addition of 50 lbs K/A.

[3] Sites high in quartz sand may benefit from the addition of 50 lbs K/A.

[4] Sand pine only.

[5] GRP = ground rock phosphate, CSP = concentrated superphosphate (triple superphosphate), DAP = diammonium phosphate.

The recommendations in Table 9 are a synthesis of data from CRIFF and the North Carolina State University Forest Fertilization Cooperative (NCSFFC). These treatments are meant to be applied approximately 8 to 10 years prior to harvest in pulpwood or small sawlog rotations and after each thinning in longer rotations. The economics of these treatments in pulpwood rotations are well worked out (Bengtson, 1971). In longer rotations with several thinnings the return on fertilization after the final thinning will far surpass that on fertilization after the first thinning; however, significant production gains in timber volume, as well as other resource values, can be obtained by fertilization after each thinning.

As with recommendations for fertilization at time of planting these recommendations are based largely on tree volume response, but other resource values will also benefit. These broader benefits may call for the use of more complex fertilizers; however, the data on which to recommend such mixtures is almost totally lacking.

If more precision in determining probability of response to fertilization is desired foliar analyses or regression equations (Kushla and Fisher, 1980) may be used.

Critical Foliar Concentrations (%)

	N	P	K	Ca	Mg
Slash Pine	<1.0	<.09	<.30	<.10	<.06
Loblolly Pine	<1.0	<.11	<.30	<.10	<.06

The response, particularly in loblolly pine, may be quite dependent on stand conditions and the guide developed by NCSFFC (Report No. 1) may be used if the stands are to be fertilized without thinning.

Table 9.--Recommendations for fertilization at mid-rotation for pulpwood or after thinning for longer rotations.

Soil Group	Treatment	Probability[1] of Response	Volume Gain[1] $ft^3A^{-1}Yr^{-1}$
A	150 lbs N and 50 lbs P/A[2] as GGRP[3] and urea	100%	45 - 75
B	150 lbs N and 50 lbs P/A[2] as GGRP, CSP, or DAP and urea	90%	20 - 60
C	150 lbs N and 50 lbs P/A[2] as GGRP, CSP or DAP and urea	75%	25 - 55
D	150 lbs N and 50 lbs P/A[2] as GGRP and urea	75%	45 - 90
E	150 lbs N and 50 lbs P/A[2] as CSP or DAP and urea	90%	30 - 50
F	150 lbs N and 50 lbs P/A[2] as CSP or DAP and urea	50%	10 - 40
G	Fertilization not recommended	0%	0
H	150 - 300 lbs N and 50 lbs P/A[2] as GGRP and urea	75%	20 - 60

[1] Estimated from over 50 CRIFF and NCSFFC trials with slash, loblolly and and sand pine.

[2] Stand fertilized with P at time of planting need not be refertilized with P.

[3] GGRP = granulated ground rock phosphate, CSP = concentrated superphosphate (triple superphosphate), DAP = diammonium phosphate.

Conclusion

The southeast and gulf coastal plains are unique in the ease and accuracy with which soil information can be used in silvicultural practice. This is partially due to the rather uniform climate and the very simple soils. However, much of the precision in our ability to use soils as a guide in silviculture comes from the long history of interest in forest soils, and from the many experiments carried out by university-industrial cooperatives, the Forest Service and independent university and industrial scientists.

The majority of the information in this paper has been derived from the observations of the author and/or his interpretation of other's observations or data. The responsibility for the accuracy and truth of these contents is wholly that of the author and not that of any other individual or organization named or unnamed.

The responsibility for improving the accuracy and precision of soils interpretations for silviculture rests not only with the author and other research workers, but also with the foresters who use the information. The best way to test soils interpretations for silviculture is by observation of the results of their use in the field. The feedback from farmers has aided immensely in the development of soils interpretations for agriculture. As these preliminary soils interpretations are used we must observe the results and then further modify our recommendations. In this way we should be able to rapidly refine the recommendations and greatly improve their usefulness.

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RESEARCH ON
ENVIRONMENTAL AND SITE EFFECTS OF FOREST MANAGEMENT PRACTICES IN THE LOWER COASTAL PLAIN[1]

H. Riekerk, L. F. Conde, J. C. Hendrickson, and W. S. Gain[2]

Abstract.--Integrated research is identified in terms of disciplines, funding sources, and levels of resolution. A research program is described focusing on site and environmental effects of silvicultural management practices ranging from standard pulpwood to short-rotation fuelwood production. Some preliminary data is presented on the pulpwood silviculture studies suggesting first-year negative effects in the poorly drained flatwoods forests. Eucalyptus fuelwood plantings appear to have higher water use.

INTRODUCTION

Research integration aims at focusing several disciplinary teams on a general problem preferably coordinated for one area. The overall research objective is broken down into sub-objectives which are to be achieved by the disciplinary teams in an integrated fashion. Periodic review and communication between teams is required to coordinate levels of resolution for data acquisition and synthesis, methods and units of measurement, and logistics. Integration of different funding sources into one research program can also be accomplished by subcontracting research components to specific interests of funding agencies but within the umbrella of the overall research objective.

This report describes such integration of the latter kind and presents preliminary information from the advanced components of ongoing studies in a research program focused on evaluation of environmental and site effects of intensive forest management practices in the Lower Coastal Plain of Florida.

The overall objective of the research program is to evaluate and predict the environmental and site effects resulting from intensive forest management practices. Environmental and site effects include changes of water blances, non-point source pollution, and changes in soil-plant nutrient levels.

The research strategy is a) to impose an intensity range of silvicultural practices on calibrated watersheds to measure hypothesized treatment effects of large-scale operations and, b) to attempt to explain observed treatment effects by measurements of hypothesized mechanisms with more detailed plot studies within the watersheds or elsewhere when appropriate.

Sub-objectives identified are a) evaluation of effects resulting from a range of biomass removal and regeneration operations (Table 1A) and, b) evaluation of effects resulting from fuelwood silviculture in a range of tree-soil-climate conditions of Florida (Table 1B). The latter has two phases: 1) pilot plot studies and 2) small operational watershed studies of promising tree-soil-climate combinations.

The range of biomass removals in watershed scale studies varies from the undisturbed control, to standard pulpwood, to whole-tree, to total living biomass removal. The degree of site disturbance varies from the undisturbed control, to minimum, medium, and maximum soil exposure by standard harvesting-regeneration techniques. Minimum soil exposure is achieved with manual

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[1] Paper presented at the Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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shortwood harvesting, mechanical drum chopping of slash, bedding and planting. Medium soil exposure includes tree-length harvesting, slash burning, chopping, bedding and planting. Maximum soil exposure is achieved with mechanical tree-length harvesting, stump removal, slash burning, windrowing, bedding and planting.

The fuelwood silviculture plot trials include six tree species at three locations in Florida. Each species is being evaluated at two high planting densities for growth, yield, site requirements, and environmental effects. In addition, three of the species are also being tested on very small watersheds to assess non-point source pollution and water use effects.

The research program is being supported by funds from half a dozen institutions. The U.S. Forest Service initiated the overall program in 1977 with three isolated watersheds (WS 1-3) ranging from 48 to 136 hectares (IMPAC studies), expanded with a 4-hectare semi-isolated watershed (WS 6) for water quality monitoring of an intermediate intensity level of forestry practices, in Florida's poorly drained flatwood forest lands. The main objective of this integrated study is to evaluate the impacts of intensive forest management practices on the hydrology and water quality of Florida's flatwoods ecosystems. Two additional isolated 4-hectare watersheds (WS 4-5) have been constructed with funds from the Oak Ridge National Laboratory (Solar Whole-Tree). The objective of this study is to evaluate the environmental impacts and long-term site degradation of whole-tree harvesting in pulpwood and fuelwood silviculture. A 0.4-hectare waterbed study has been funded by the University of Florida to assess environmental and site effects of coal-ash utilization in _Casuarina_ spp. silviculture. _Casuarina_ is a nitrogen-fixing tree species.

Small 0.01-hectare lysimetric plot studies of water use, nutrient requirements, and soil water quality of six fuelwood tree species have been funded by the Department of Energy (Energy and

Table 1.

A. Watershed studies of biomass removal and site preparation effects.

	Biomass Removal			
	None	Pulpwood	Aboveground	Total
Soil Exposure	Control	Stem	Stem, crown	Stem, crown, stump
None Fire control	WS 3			
Minimum Chopping, bedding		WS 1		
Medium Burn, chop, bed		WS 6	WS 4	
Maximum Burn, windrow, bed		WS 2		WS5, WS 7[1]

[1] Note: for fuelwood silviculture with _Eucalyptus_ and _Casuarina_, respectively.

B. Plot studies of fuelwood species, plant spacing and Florida sites.

Site and species	Plant Spacing (m)		
	2x3	1x1.5	1x0.5
N. Florida			
Sand pine	PL 1	PL 2	PL 3
C. Florida			
Slash pine	PL 4	PL 5	PL 6
Eucalyptus		PL 7	PL 8
S. Florida			
Casuarina		PL 9	PL 10
Eucalyptus		PL 11	PL 12
Melaleuca		PL 13	PL 14

Chemicals from Woody Species). The main objective of this study is to evaluate sand pine in North Florida, slash pine and Eucalyptus viminalis in Central Florida, and E. grandis, Casuarina cunninghamiana, C. equisitifolia, and Melaleuca quinquenervia in South Florida, for high-density fuelwood plantation management and assess associated requirements for soil and water resources.

A waterbalance study of slash pine with a weighing lysimeter has been supported by the Florida Water Resources Research Center since 1978. The objective of this study is to calibrate metereological methods of evapotranspiration assessment which then can be used to independently measure evapotranspiration of the watershed-level waterbalance studies.

PROCEDURES AND PRELIMINARY RESULTS

Watershed Studies

Three large watersheds (WS 1, WS 2, WS 3 in Figure 1) were established in the poorly drained pine flatwoods ecosystems of central Florida during 1977. Isolation was accomplished by road-dike systems and hydrology and water quality monitored with longthroated flumes (Riekerk et al., 1978). Minimum (WS 1), medium (WS 6), and maximum (WS 2) harvesting-regeneration practices were imposed during 1979 and environmental effects compared against control (WS 3) (Riekerk et al., 1980). Water quality data only from the semi-isolated intermediate treatment (WS 6) is included in this report. Hydrologic information from the three isolated watersheds is presented in Table 2 and Figure 2.

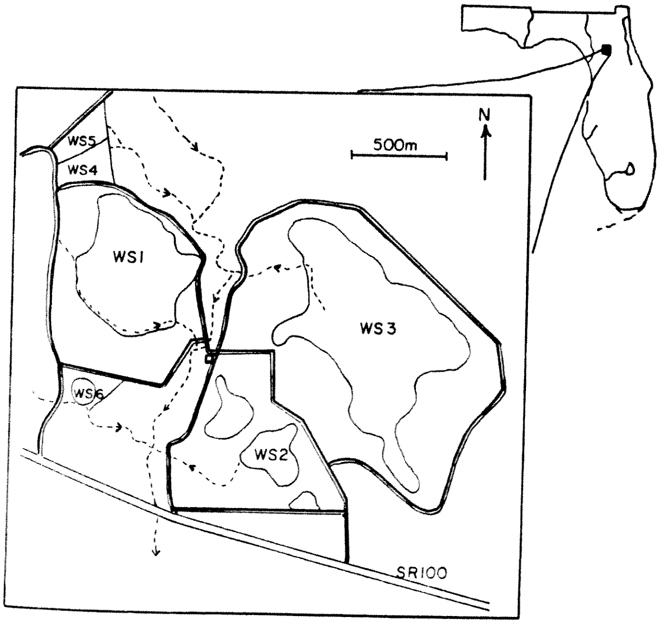

Figure 1. Bradford Forest Watersheds.

Rainfall during the baseline year was somewhat higher than normal due to a few large events. Continuous soil saturation resulted in high water yields (39 percent of rainfall) which normally are less than 10 percent. Groundwater seepage was measured as less than one percent of precipitation input. The maximum disturbance treatment (WS 2) denuded the harvested areas resulting in a 165 percent increase in water yield. The minimum disturbance treatment left significant transpiring vegetation cover which limited the increase of water yield to 66 percent.

Water quality data are summarized in Table 3. With an average coefficient of variation of 40 percent between three watersheds, significance at the 10 percent level of confidence occurs when treatments differ by a factor of 2 from the control. Between-year differences as exemplified by control WS 3 have been accounted for by attaching treatment significance only to differences of between-year ratios.

Treatments did not have any effect on runoff pH, but significantly decreased ammonium-nitrogen levels proportional to treatment intensity. Observed increases of soil solution ammonium levels (Morris and Pritchett, 1980) would suggest significant fixation-sink or gaseous-loss pathways. Treatments had little or no effect on the levels of nitrogen and phosphorus species in runoff waters. Of the cations calcium and potassium levels appeared to be increased by treatments. The increase was highest during the first few months immediately following harvesting operations (Figure 2). Strangely, suspended sediment levels have been increased inversely to soil exposure. Observations of sediments in traps suggest very little movement of bedload.

Water quality data from upland forested watersheds after clearcutting are summarized in Table 4. From this generalized data it is apparent that the Bradford flatwoods forest treatments increased only cation levels in runoff water as compared to upland forest treatments.

Nutrient balance data of precipitation input minus runoff output are summarized in Table 5. Increases in retention are apparent for most cations, especially in maximum treatment WS 2. This suggests fixation by the denuded forest soil to be an important buffer mechanism. Net phosphorus output has been increased from the maximum treatment WS 2 treatment suggesting soil-release processes (more reduced conditions?) to be dominant. The positive balances and the increased retention of cations by severe disturbance suggests these forested watershed ecosystems to be nutrient-poor and of an oligotrophic nature.

In conclusion, it appears that the levels of management intensity increased runoff but decreased ammonium (and nitrate) levels during the first year. Nutrient levels of runoff from the oligotrophic flatwoods forest ecosystems were comparable to treatment effects of upland forested watersheds.

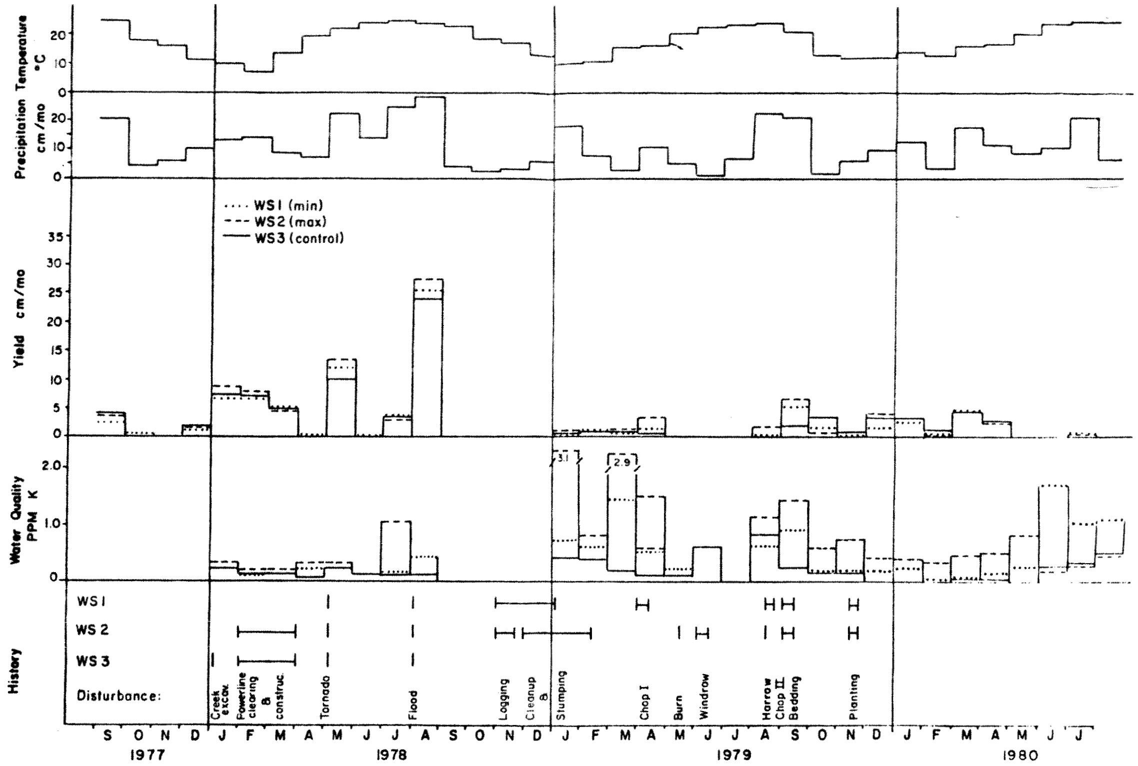

Figure 2. Climate, runoff and water quality patterns of Bradford Forest Watersheds.

Table 2. Hydrologic summary (cm/yr).

	1978 Total WS Observed	1979 Total WS Observed	1979 Total WS Predicted[1]	1979 Harvested Area	1979 Percent Increase
Rainfall	151.1	129.5	---	---	---
Yield					
WS 1 (Y_1)	58.4	11.4	8.2	13.6	66
WS 2 (Y_2)	62.0	16.4	7.4	19.6	165
WS 3 (X)	56.9	9.2	---	---	---

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[1] From equations for monthly values:

$Y_1 = 1.13\ X - 0.20$ and $Y_2 = 1.28\ X - 0.51$; $R^2 = 0.98$, $S_{\bar{Y}} = 1.0$ cm.

Table 3. Runoff water quality comparisons.

		pH	NH_4N	NO_3N	TKN	PO_4P	TP	Ca	Mg	K	Sed
		units	ppm								
Runoff	'78	3.6	0.10	0.03	0.67	0.036	0.04	1.21	0.98	0.28	3.5
WS 1	'79	3.7	0.06	0.03	1.37	0.039	0.02	1.38	0.88	0.61	5.0
Ratio		1.3[1]	0.6[2]	1.0[2]	2.0	1.1	0.5	1.1[2]	0.9[4]	2.2	1.43[2]
Runoff	'78[3]	3.7	0.08	0.02	0.93	0.024	0.06	1.83	0.91	0.30	--
WS 6	'79	3.9	0.07	0.04	1,84	0.033	0.05	1.80	1.50	0.30	--
Ratio		1.6[1]	0.9[2]	2.0	2.0	1.4	0.8	1.0[2]	1.6	1.0	--
Runoff	'78	4.1	0.09	0.02	1.15	0.017	0.11	3.00	1.09	0.48	37.2
WS 2	'79	4.0	0.12	0.05	1.24	0.018	0.02	1.06	1.45	1.30	10.0
Ratio		0.8[1]	1.3[2]	2.5	1.1	1.1	0.2[2]	0.4	1.3	2.7[2]	0.27[2]
Runoff	'78	3.6	0.06	0.01	0.97	0.018	0.04	1.27	0.65	0.13	70.6
WS 3	'79	3.6	0.25	0.03	1.62	0.027	0.02	0.51	1.26	0.15	3.3
Ratio		1.0[1]	4.2	3.0	1.7	1.5	0.5	0.4	1.9	1.2	0.05

[1] Ratio of hydrogen ion concentrations.

[2] Significant treatment effect at the 10 percent level of confidence.

[3] Average of WS 1, 2, 3 data.

Table 4. Runoff water chemistry changes due to clearcutting (ppm).

	NO_3N		P		K		Ca	
	Control	Cut	Control	Cut	Control	Cut	Control	Cut
<u>Florida</u>								
(Hollis et al. 1979)	0.01	0.05	0.03	0.28				
(This paper)	0.03	0.04	0.02	0.03	0.2	0.7	0.5	1.4
<u>Georgia</u>								
(Hewlett 1979)	0.11	0.02	0.34	0.34	1.3	1.3	5.6	2.7
<u>North Carolina</u>								
(Douglass & Swank 1975)	0.005	0.009	0.004	0.004	0.4	0.5	0.6	1.0
<u>West Virginia</u>								
(Aubertin & Patric 1974)	0.10	0.49	0.02	0.04	0.5	0.6	0.8	0.7
(Patric 1980)	0.35	0.41	0.01	0.01	0.7	0.6	1.1	1.0
<u>Pennsylvania</u>								
(Mussalem & Lynch 1980)	0.08	0.37			1.0	1.1	5.8	3.2

Table 5. Nutrient balances (kg/ha/yr).

		NH_4N	NO_3N	TKN	PO_4P	P	Ca	Mg	K	Sed.
WS 1	1978	+2.2	+4.2	+8.4	+0.2	+2.6	+3.7	-1.8	+1.0	-21.0
	1979	+1.8	+2.3	+4.3	0.0	+0.6	+1.3	+2.7	+2.4	-6.4
Min.	Ratio	0.8	0.6	0.5[1]	n.a.	0.2	0.4	0.6	2.4	0.30[1]
WS 2	1978	+2.2	+4.0	+6.1	0.0	+0.5	-4.5	+0.4	+0.4	-153.2
	1979	+1.8	+2.8	+4.7	0.0	+0.3	+1.3	+1.5	+1.8	-17.5
Max	Ratio	0.8	0.7	0.8[1]	n.a.	0.6[1]	0.2[1]	3.8[1]	4.5[1]	0.11[1]
WS 3	1978	+2.2	+4.1	+1.4	0.0	+0.6	+5.9	+1.8	+1.6	-398.6
	1979	+1.7	+3.0	+5.0	0.0	+0.2	+2.3	+1.0	+2.5	-2.7
Control	Ratio	0.8	0.7	3.6	n.a.	0.3	0.4	0.6	1.6	0.01

[1] Significant at the 10 percent level of confidence.

Two smaller adjacent watersheds (WS 4 and WS 5) were constructed during 1980 using road-dike and buried plastic-wall boundaries (Figure 3). Vegetation analyses show a biomass of 104 mt/ha containing 156 kg/ha N, 12 kg/ha P, 30 kg/haK, and 188 kg/ha Ca. The forest floor contains about 290 kg/ha N and 9 kg/ha P, while the rooted soil contains approximately 2300 kg/ha N and 10 kg/ha P (Morris, unpublished data). Apparently most nitrogen is stored in the soil component of the flatwoods forest ecosystem. Preliminary runoff water quality data of these new watersheds are included in Table 6. This information shows some differences with that of the well-established control WS 3 which may be due to recent disturbances from watershed construction. Baseline water chemistry at sampling stations downstream of WS 4 and WS 5 is being monitored to assess watershed treatment effects on stream processing during 1981.

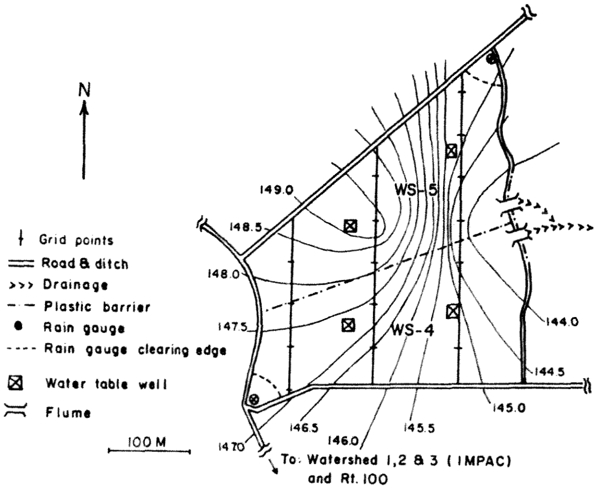

Figure 3. Map of WS 4 and WS 5 of the Bradford Forest research area.

Table 6. Water quality of WS 3, WS 4, WS 5, and downstream sample points.[1]

	TKN	TP	K	Ca	Mg
WS 3	1.01	0.022	0.05	0.30	0.50
WS 4	0.56	0.028	0.20	1.20	1.90
WS 5	0.92	0.034	0.20	1.20	1.10
ST 1	0.72	0.019	0.24	0.47	0.90
ST 2	1.13	0.023	0.30	0.40	0.90
ST 3	1.31	0.020	0.11	0.37	0.93
ST 4	1.12	0.022	0.20	0.77	1.21

[1] Spaced about 100 m. apart.

Two small 0.5-hectare watersheds with plastic-wall boundaries are under construction on poorly drained and acid flatwoods soil and will be amended with 100 mt/ha of unweathered coal ash. These areas will be planted in high-density fuelwood spacing with Casuarina spp. during 1981. Soil site and environmental effects, nitrogen fixation by Casuarina, and fuelwood production will be monitored to evaluate the environmental and site impacts of fuelwood silviculture utilizing coal ash amendments.

Plot studies

Smaller lysimetric plots have been developed since 1978 to evaluate the site requirements and environmental effects of fuelwood silviculture with tree species adapted to the different soil and climate conditions of Florida (See Table 1B). Fuelwood silviculture utilizes high-density spacing and very short rotations. Productivity of these stands can be double that of standard pulpwood spacing in short rotations (Table 7).

Table 7. Biomass yields for fuelwood and pulpwood species.[1]

Species	Age (yrs)	Spacing (m x m)	Yield (mt/ha/yr)
Fuelwood			
Slash pine	8	0.6 x 0.6	4.9
Sand pine	6	0.6 x 0.6	7.2
Casuarina	4	1.0 x 1.0	8.3
Melaleuca	3	0.3 x 0.3	13.9
Melaleuca	9	0.6 x 0.6	28.5
Pulpwood			
Eucalyptus	7	2.4 x 2.4	4.5
Slash pine[2]	9	2.7 x 3.7	3.4

[1] Adapted from Conde and Rockwood, 1979.

[2] From Manis, 1977.

Water monitoring in these plots requires different techniques dependent on the site conditions. The deep and excessively drained sandy soils under sand pine in north Florida are being monitored with porous filter tubes at 0.1 atm tension inserted laterally at 2 m depth from a manhole and sub-sampled monthly. Preliminary data suggest only a few percent of precipitation percolated during the summer months with no percolation during the drier spring months when soil moisture dropped below 6 percent by weight (Figure 4). No effects due to planting density of sand pine is yet apparent in soil moisture regimes.

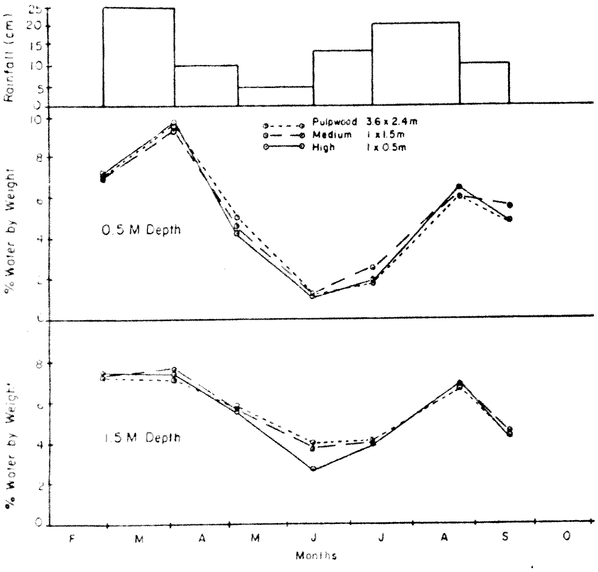

Figure 4. Soil water content in N. Florida sand hills.

The shallow and poorly drained sandy flatwoods soils in North-Central Florida are being monitored with lysimetric plots. Impermeable walls have been constructed down into the underlying clay layer forming an isolated soil monolith (Figure 5). Watertable control and water sampling is with forced drainage. Preliminary watertable data suggest significantly more water use (3 cm) by the high-density (0.5 x 1.0 m) *Eucalyptus* plot than by the low-density (1.5 x 1.0 m) or pulpwood (2.0 x 3.0 m) pine plots. The low-density *Eucalyptus* and high-density pine plots also show more water use, but not significantly so.

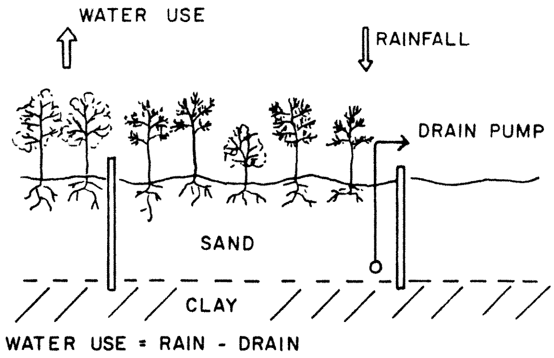

Figure 5. Lysimetric plot diagram.

The deep and poorly drained sandy palmetto-prairie soils in south Florida have been isolated laterally with 1.2 m plastic walls. Monitoring of daily watertable fluctuations provides water-use information (Gray, 1970). Some data has been obtained and no differences in watertable regimes have been observed as of this time.

A small (7.2 m^2) weighing-lysimeter plot has been constructed in the poorly-drained flatwoods soil of north-central Florida and planted to standard pulpwood tree spacing (Figure 6). The hydraulic weighing lysimeter consists of two nested 1.2 m deep fiberglass tanks, the inner one backfilled with soil and provided with forced drainage. Precipitation and weight changes are being monitored continuously to estimate actual evapotranspiration outputs accurately. Equations for calculated potential evapotranspiration rates from adjacent weatherstation data can then be corrected and used for independent evapotranspiration estimates of the large watershed studies. The actual evapotranspiration data from the weighing lysimeter will also be used to check the waterbalances of adjacent lysimetric plots planted in pine pulpwood spacing.

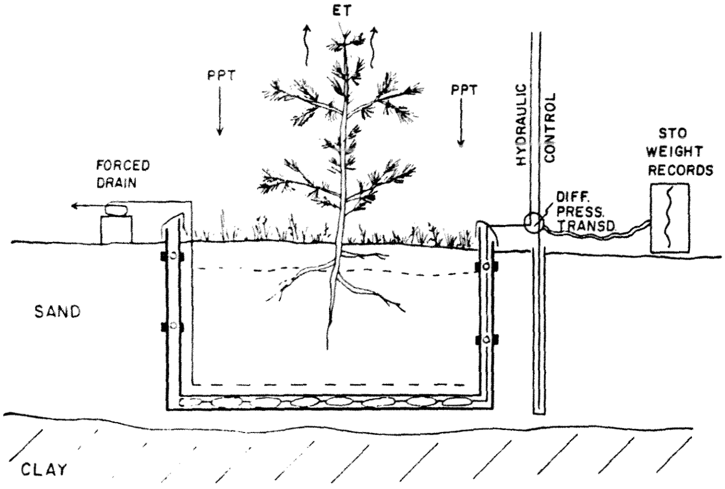

Figure 6. Weighing lysimeter diagram.

CONCLUSIONS

The environmental and site effects research program has been developed with resources from a variety of funding agencies interested in specific aspects of silvicultural impacts. Overlapping use of research facilities provides mutual support reinforcing the data obtained for specific interests. Reporting of results will become more integrated over time with managerial and regulatory applications for silvicultural practices at various levels of intensity.

Preliminary information suggests pulpwood silviculture in the flatwoods physiography to generate lower levels of nitrogen species and higher levels of nutrient cations in runoff water quality. This seems to be the reverse of results reported for upland watershed studies in the northeastern U.S. The water regime of the regenerated sand hill forest in northern Florida appears to be strongly dominated by evapotranspiration losses with only a few percent of precipitation percolating to groundwater. Eucalyptus spp. appears to be performing well in fuelwood experimental plots as compared to other tree species. Some increased effect on water use has been documented so far.

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FOREST AND RANGE INTERACTIONS[1]

Henry A. Pearson[2]

Abstract.--This paper provides information collected on forest, range, and wildlife interrelationships and projects economic values from livestock in the forest program. Data presented are mainly from range research studies, Alexandria, Louisiana, but include some cooperative research and literature review.

INTRODUCTION

Judicious multiple-use planning offers numerous social and economic benefits and requires few concessions from land managers. An important advantage of integrated tree and livestock management is that profit can be higher than with single-resource management. Changing markets encourage flexibility in the overall operation because diversification provides a means of surviving poor markets. Dominant issues in the future will be to overcome commodity shortages--food and fiber--and to protect the environment. Sound multiple-use management of timber lands will enable the landowner to meet both challenges at a profit. However, all disciplines must work cooperatively to accomplish these goals.

The purpose of this paper is to provide information regarding (1) the effects of trees on forage for livestock and wildlife, (2) the effects of cattle on pine regeneration, (3) livestock-wildlife relations, and (4) the economics of adding livestock to the forest program. Hopefully, this paper will show that the forage resource on southern forests is an asset and not a liability. In light of current and future demands on land resources, simultaneous management of timber, livestock, and wildlife is imperative. Southern pine forests have the climate, soils, water, and light necessary to produce good forage and timber (Duvall 1973).

TREES AND FORAGE

Overstory tree density, or canopy, has the greatest influence in determining forage yields. Yields decrease as tree overstory increases (Gaines et al. 1954; Halls and Schuster 1965). In 13- to 17-year-old longleaf and slash pine stands, forage yields decrease about 15 lb/acre for every 1 ft^2 basal area tree increase (Wolters 1973). In 35- to 40-year-old longleaf pine stands, yields decrease about 7 lb/acre for every 1 ft^2 increase (Grelen and Lohrey 1978). Canopy even influences forage nutrients; for instance, forage protein content is higher under shade than in the open (Wolters 1973). Growing cool-season exotics under pine stands does not provide more forage than natives, but can provide green forage during winter when natives are dormant (Pearson 1975).

Any forest management practice that alters the overstory will change forage potentials. Reforestation practices greatly influence the forage available. Wide spacing, such as 10 x 12 ft, or 12 x 12 ft, yield more forage than do closer spacings. Forage yields of 1000 lb/acre were produced through age 16 under slash pines regenerated at 6- x 12-ft spacings (Lewis 1973). Direct-seeded stands usually reduce production sooner than planted stands because trees are generally denser in direct-seeded stands (Pearson et al. 1971; Pearson 1974).

A 12-year-old direct-seeded slash pine stand, precommercially thinned to 500 trees per acre at age 3, produced about four times more forage than unthinned stands (Grelen et al. 1972). If burned and thinned regularly, mature longleaf pine stands provide about half as much forage as treeless range (Grelen and Enghardt 1973; Derr and Enghardt 1969).

Fertilizing the forest to increase tree growth also improves forage quality and yields

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[1] Paper presented at the Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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(McMinn 1966; Lewis 1970; Duvall and Grelen 1967); however, fertilization may not be economical for meeting livestock nutritional requirements (Duvall and Grelen 1967). In fertilized pastures pulpwood yields were 2.7 times more than on nonfertilized range (Burton 1973). Cattle on plots with no trees averaged 0.99 lb daily weight gain (247 lb/acre annually), cattle where trees were spaced 20 x 20 ft gained 0.86 lb daily (178 lb/acre), and those on plots 12- x 12-ft spacings gained 0.77 lb daily (120 lb/acre).

Timber supplies apparently are not greatly reduced even with wider tree spacings. Yields of unthinned slash pine sawtimber were greater from 200 trees/acre after 30 years than from 600 trees/acre thinned to 400 trees at age 15, to 300 at age 20, and to 200 at age 25 (Bennett 1971). At ages 20 to 35 years the cubic yield of 200 trees/acre was over half the yield from 1000 trees, and the yield from 600 trees was 90 to 98 percent of the 1000-tree yield (Bennett 1963).

LIVESTOCK AND PINE REGENERATION

Uncontrolled livestock may graze or trample pine regeneration; however, damage can be reduced or eliminated through management. Guidelines to reduce cattle damage to slash pine (*Pinus elliottii* Engelm.) regeneration involve mainly prescribed winter rotational burning for livestock distribution and regulation of grazing intensity (Pearson et al. 1971). Planted and direct-seeded slash pine were successfully regenerated with light and moderate grazing intensities. We found only heavy grazing (60 percent utilization of the forage supply) significantly reduced pine survival (about 20 percent in planted stands). Avoiding late winter and spring grazing during establishment and the first year alleviates most of the damage problems even with high stocking rates. Changing the location of supplemental feeding or mineral stations also helps in livestock distribution.

On longleaf pine (*P. palustris* Mill) regeneration areas in Alabama, moderate grazing by cattle did not harm seedlings during establishment and the first growing season (Boyer 1958). Later observations indicated a decline in longleaf pine survival on grazed range; however, grazing did not follow the guidelines given above (Boyer 1967). Direct-seeded longleaf pine regeneration in Louisiana was highly variable (50 to 1500 trees/acre); however, no significant differences in survival were found between moderately grazed and ungrazed plots (Pearson 1980).

Pines appear highly resistant to grazing damage. In an attempt to simulate grazing damage on pines in Georgia, researchers inflicted several types of injury on slash pine seedlings. It included removing needles, removing the growing shoot, bending the stem horizontally, and stem girdling (Lewis 1980). These injuries were applied in varying degrees and combinations to seedlings at 6, 18, and 30 months after planting. Slash pines--and possibly other pines--apparently recover quickly from most of these injuries. Mortality was high only when all foliage and shoots were removed and stems were bent horizontally (Lewis 1973). Shortleaf (*P. echinata* Mill.) and loblolly pines (*P. taeda* L.) browsed within an inch or two of the ground by rabbits survived and grew as well as unbrowsed trees (Wakeley 1970).

In cases where cattle or deer congregate in small openings and seriously damage young pines, livestock populations must be regulated to coincide with forage supplies in the openings. Deferred or seasonal grazing until trees are 8- to 10-ft tall will also reduce damage (Cassady et al. 1955). Preliminary findings on loblolly pine plantations in 40- to 60-acre clearcuts within large site-dominating timber stands (2,000 acres) indicate some losses with continuous cattle grazing. However, natural loblolly pine seedings from trees on the perimeters of the relatively small clearcuts resulted in exceptionally high tree densities on all treatments (Pearson 1980).

Animal repellents such as copper carbonate, tetramethylthiuram (TMTD), or zinc dimethyldithiocarbanate cyclohexylamine (ZAC) help, but have not been completely successful for either deer or cattle (Duvall and Whitaker 1959; Denton et al. 1969). Windrowing debris around vulnerable plantations provides some protection, even against deer.

Some tree benefits may accrue through a multiple-use management program where grazing reduces competition before pine regeneration and removes hazardous fuels (Pearson 1974). The key to success is maintaining a balance between forage and animals and animal distribution.

CATTLE AND DEER

Livestock and wildlife programs can be mutually beneficial. For example, livestock grazing can benefit wildlife by stimulating new growth. Livestock management usually provides water and supplemental feed which may be used by wildlife in times of need (Pearson 1969). Hunting leases can provide an additional source of revenue for the forest landowner. These multiple uses, when properly managed, also foster good public relations in the local community.

When livestock and wildlife exceed food supplies, undesirable competition is created and resources may be damaged. Overuse by livestock for long periods is detrimental to plant composition and yield and can cause soil and site conditions to deteriorate (Duvall and Linnartz 1967). Excessive use by big game will have similar effects and cause damage to nearby agricultural crops.

Several recent studies have sought to determine the extent of overlap in cattle and deer diets at different times of the year. In Mississippi pine and pine-hardwood forests, grass use was the most apparent dietary overlap (Mitchell et al. 1979). The major deer diets consisted of mast, mushrooms, grasses, and browse. Although cattle consumed some browse, their diet was composed chiefly of grasses, varying from 77 percent in April to 99 percent in summer and fall.

In Louisiana loblolly-shortleaf pine-hardwood forests, diet overlap between cattle and deer occurs mainly during winter on heavily forested areas or during summer on clearcuts. Fortunately, cattle prefer clearcuts or more open stands where forage abounds rather than the densely timbered stands where it is limited (Thill and Martin 1980). However, few plants shared by deer and cattle contributed more than 1 percent of either diet during any season. On clearcuts with abundant year-round herbage supplies, 88 percent of the cattle diet consisted of grasses and grasslikes (Thill 1980). The deer diet contained 70 to 91 percent browse during fall, winter, and spring, and about 35 percent in summer; grasses and grasslikes in the deer diet were likewise about 35 percent in summer, a significant overlap. On timbered sites, winter and spring diets of both deer and cattle were dominated by browse, but only five species provided 5 percent or more of both their diets. During summer and fall deer diets were mainly browse while cattle diets were grasses and grasslikes. Apparently diet overlaps will be of little significance if cattle stocking rates are determined primarily on grass production.

LIVESTOCK ECONOMICS

Comments that follow are based mainly on cooperative research with Virginia Polytechnic Institute and State University, Blacksburg, VA (VPI) and a presentation given at the New Orleans forest range and pasture symposium (Haney 1980). Cash flow information was processed through several computer programs designed to evaluate long-term forestry investments, and returns are an expression of rewards for the manager's time and capital investments. The internal rate of return and net present value are used to show the economic value from a marginal addition of livestock to the forest program.

To establish a livestock operation on the forest range, certain biological situations, management variables, and investment criteria must be defined because of the infinite number of biological-management combinations available in the South. For instance, biological variables must consider site index, forage production level and forest type. Management variables include herd size, supplementation, and timber site preparation. Investment activities consider initial and replacement costs, annual costs, and returns.

Using 1976 economic levels, 240 potential investment opportunities were 89 percent positive with 84 percent exceeding a 6 percent internal rate of return and some ranging up to 18 percent (Haney 1980). When costs and revenues were adjusted to 1979 levels for a loblolly pine-bluestem site, a variable livestock herd and pasture-supported option, the internal rate of return increased from 14 to 27 percent. Similarly the net present value more than doubled. From 17 years of data collected on the Palustris Experimental Forest in central Louisiana, rates of return varied from 0 to 40 percent depending primarily on cattle price. On a 4800-acre private nonindustrial ownership with 25-year-old slash pine, the rates of return from livestock varied from 5 to 30 percent when cattle prices ranged from $41 to $78 per hundredweight (Westman 1980).

What returns will attract the forest landowner to marginal investments in livestock? Knowledge of the variables involved plus identification of sensitive inputs to obtain appropriate returns will help reduce the risk in making these investments. Livestock economic potentials from any forest land situation can soon be routinely analyzed through a cooperative program maintained by VPI and the State and Private Forestry, U. S. Forest Service, Atlanta, Ga. The investor will still need to understand both the livestock and timber operations, potential problems and the variable markets prior to investment. As stated in the New Orleans symposium, "Attractive opportunities exist, but so do troublesome problems. Otherwise, the woods would be full of cows." (Haney 1980).

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FORAGE AND PINE GROWTH WITH CLEARCUTTING AND SITE PREPARATION[1]

John J. Stransky and Lowell K. Halls[2]

Abstract.--Total available forage yield on three loblolly-shortleaf pine-hardwood forest sites in east Texas was sampled before clearcutting and one, three, and five growing seasons after planting site preparation. All sites were planted with 1-0 loblolly pine seedlings. Total forage yield averaged 345 kg/ha in the uncut forest. Yields peaked the first summer after site preparation on the untreated control (3294 kg/ha), burned (3719 kg/ha), and chopped plots (3416 kg/ha), and in the third year on the KG-bladed plots (3167 kg/ha). By the fifth growing season total forage yield declined to 1016, 1434, 1796, and 2132 kg/ha, respectively. After five growing seasons, pine survival averaged 87 percent on KG plots, 79 percent on chopped, 63 percent on burned, and 57 percent on control plots. Mechanical site treatments resulted in better pine height and diameter growth than the burned and control treatments.

INTRODUCTION

Clearcutting, site preparation, and planting are efficient means of harvesting and regenerating southern pines. However, there is considerable disagreement as to how these silvicultural practices affect other land uses and values.

The present study was conducted to find out how forage yields, plant species composition, and the growth of planted pines are affected by various site preparation methods after clearcutting of timber on pine-hardwood forest sites of east Texas. These data are needed to help clarify the effects of silvicultural operations on wildlife habitats.

Temple-Eastex Incorporated of Jasper, and International Paper Company of Nacogdoches, Texas, provided land, machinery, and manpower to establish and maintain this study.

STUDY SITES

All three study sites are within the loblolly-shortleaf pine-hardwood forest type that covers nearly 28 million ha in the southern U.S., and reaches its westernmost extension in east Texas (Stransky 1976). All sites supported mature pine-hardwood stands before clearcutting in the fall of 1972.

The sites are part of the Gulf Coastal Plain's Quaternary deposits, which are underlain by sands, sandstones, and clays of the Tertiary's Oligocene period (Dumble 1918). Their topography is nearly level to gently sloping.

Site 1 is about 24 kilometers south of Nacogdoches, Texas, on the Stephen F. Austin Experimental Forest. The site has never been cleared for agriculture, and, based on ring counts, the timber had remained uncut for at least 50 years. Interspersed with the pines were several hardwoods as old as 117 years; the majority though were about 80 years of age. Tree basal area averaged 38 m^2/ha; 31 m^2 in pine and 7 m^2 in hardwood.

The principal pine species were loblolly pine (Pinus taeda L.) and shortleaf pine (P. echinata Mill.) in admixture with southern red oak (Quercus falcata Michx.), sweetgum (Liquidambar styraciflua L.) and winged elm (Ulmus alata Michx.).

Prominent among shrubs were American beautyberry (Callicarpa americana L.) and blackberry

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(Rubus spp.). Virginia creeper (Parthenocissus quinquefolia (L.) Planch.), grape (Vitis spp.), and greenbriers (Smilax spp.) were among the most prominent vines. Vines made up 82 percent of the understory small stems, other hardwoods 9 percent, oaks 4 percent, shrubs 4 percent, and pines 1 percent. Longleaf uniola (Uniola sessiliflora Poir.), elephant's foot (Elephantopus tomentosus L.) and twinberry (Mitchella repens L.) were common herbaceous plants.

Site 2 is near Wells, in Cherokee County, and is owned by International Paper Company. It is 16 km due west of site 1 (Nacogdoches County). The area was cleared for agriculture around 1890 and was cultivated until about 1930. The abandoned land was invaded by pines. Several hardwoods on the site were as old as 85 years, the majority being about 45 years of age. Tree basal area averaged 21 m^2/ha; 11 m^2 in pine and 10 m^2 in hardwood.

The prevalent pine species were loblolly pine and shortleaf pine. These occurred together with southern red oak, post oak, water oak, sweetgum, and winged elm.

Principal shrubs were American beautyberry and blackberry. Virginia creeper, grapes, and greenbriers were the most prominent vines. Vines made up the greatest proportion of small stems (35 percent), followed by shrubs (33 percent), other hardwoods (17 percent), oaks (12 percent), and finally pines (3 percent). Most common herbaceous plants were longleaf uniola, pinehill bluestem (Andropogon spp.), and panic grasses (Panicum spp.).

Site 3 is about 80 km southeast of site 1 near Jasper, in Jasper County, Texas. It is owned by Temple-Eastex Incorporated. The site had never been cleared for cultivation but it had been grazed by livestock. The area supported a 45-year-old forest stand. Tree basal area averaged 24 m^2/ha; 18 m^2 in pine and 6 m^2 in hardwoods.

The principal tree species of the overstory were loblolly pine, shortleaf pine, southern red oak, water oak, post oak, willow oak (Quercus phellos L.), sweetgum, and blackgum (Nyssa sylvatica Marsh.).

The midstory was about 30 years old, consisting mainly of the same species as the overstory, plus American holly (Ilex opaca Ait.), red maple (Acer rubrum L.), mockernut hickory (Carya tomentosa Nutt.), and flowering dogwood (Cornus florida L.).

Common shrubs were American beautyberry, yaupon (Ilex vomitoria Ait.), blackberry, blueberry (Vaccinium spp.), and southern wax-myrtle (Myrica cerifera L.). Prevalent vines were yellow jessamine (Gelsemium sempervirens (L.) Ait.), muscadine grape (Vitis rotundifolia Michx.), and greenbriers. Vines made up 47 percent of the understory stems, shrubs 34 percent, other hardwoods 10 percent, oaks 6 percent, and pines 3 percent. Longleaf uniola, elephant's foot, and twinberry were the most abundant herbaceous plants.

METHODS

Site Treatments

The study had a randomized block design consisting of three adjacent blocks and four site treatments on each of the three sites. Individual site treatment plots were 0.6 ha squares. After the merchantable trees were cut and removed from the three study areas in the fall of 1972, the following site preparation treatments were applied during February and March 1974 on site 3, and during August and September 1974 on sites 1 and 2:

Control--No site preparation, all woody stems greater than 2.5 cm in diameter at breast height (dbh) were cut.
Burn--all stems greater than 2.5 cm dbh were cut and burned with the logging slash by head fires.
Chop--logging slash and all stems were cut with a chopper and burned.
KG--all stems were cut with a KG blade, and the logging slash was raked off the plots and burned. Sites 1 and 2, but not site 3, were cultivated with a heavy-duty disk after having been KG bladed.

The sites were handplanted with 1-0 loblolly pine seedlings at 2.4 by 3 m spacing. Site 3 was planted in mid-March 1974, and sites 1 and 2 in February and March 1975.

Vegetation Measurements

In the summer of 1972 and 1973 before and one year after timber cutting, the vegetation on all three sites was inventoried and forage yield sampled on 20 1-m^2 quadrats equally spaced within the central 0.4 ha of each 0.6 ha plot. The inventory and forage yield sample was again taken one, three and five growing seasons after site preparation. Site 1 was sampled in the summers of 1975, 1977, and 1979; site 2 only in the summers of 1975, and 1977; site 3 in the summers of 1974, 1976, and 1978. The annual growth of all herbaceous and woody plants was clipped up to a height of 1.5 m, dried at 70° C, and weighed to the nearest 0.1 g. We grouped these data to show yields in kilograms per hectare (kg/ha) for herbage (grasses, grasslike species, legumes, composites, and other forbs), and browse (pines, oaks, other trees, shrubs, and vines). Plant nomenclature followed Gray's Manual of Botany (Fernald 1970).

Pine seedling survival was tallied on randomly selected rows at all three sites at the end of the first and the fifth growing seasons after planting. Tree heights and diameters (dbh) were measured after the fifth growing season, and observations were made on crown class and insect damage.

For all data, differences among treatments were tested by analysis of variance at the 0.05 level of significance, and by Duncan's test.

RESULTS AND DISCUSSION

Forage Yield

Before Clearcutting (1972)

On site 1 total forage yield in the uncut timber ranged from 258 to 356 kg/ha, averaging 328 kg/ha. Of this 232 kg/ha were browse (70 percent), and 96 kg/ha were herbage -- mostly grass (30 percent). Thus, available browse greatly outweighed herbage (Table 1).

Species contributing most to browse yields were mockernut hickory, flowering dogwood, sweetgum, poison ivy (Rhus radicans L.), and rusty blackhaw (Viburnum rufidulum Raf.). Longleaf uniola contributed 79 percent of the total herbage yield.

On site 2 total forage yield ranged from 287 to 384 kg/ha, averaging 347 kg/ha. On this formerly cleared site, browse species contributed only 40 percent of the total forage, mostly Virginia creeper, greenbriers, post oak, sweetgum, winged elm, and American beautyberry. Longleaf uniola contributed 54 percent of the herbage. Along with panic grasses, pinehill bluestem, and longleaf uniola, grasses amounted to 68 percent of the total herbage.

On site 3 total forage yield ranged from 309 to 383 kg/ha, averaging 359 kg/ha. Browse species averaged 86 percent of the total, mostly yaupon, yellow jessamine, and sweetgum. Longleaf uniola, twinberry, and elephant's foot constituted 91 percent of the herbage yield.

After Clearcutting (1973)

On site 1, one growing season after clearcutting, forage yields ranged from 1330 to 2058 kg/ha, averaging 1714 kg/ha; a fivefold increase over the uncut stand. The most obvious feature of the post-cutting yield pattern in 1973 was the great increase in grasses and other herbaceous plants (Table 1).

The greatest total yields were obtained on the control and burned plots from which small pines and culls were cut by hand soon after the merchantable overstory was harvested. The KG and chop plots yielded less total forage because they still contained leftover cull trees. The proportion of herbage too, was less on these plots than on the other treatments.

Browse species contributing most to forage yield were American beautyberry, Virginia creeper, grapes, southern red oak, sweetgum, and winged elm.

Table 1.--Forage yield by sites, site treatments, and sampling dates

Forage	Control					Burn					Chop					KG				
	Before cut	After cut	Years after site preparation 1st	3rd	5th	Before cut	After cut	Years after site preparation 1st	3rd	5th	Before cut	After cut	Years after site preparation 1st	3rd	5th	Before cut	After cut	Years after site preparation 1st	3rd	5th
										kg/ha										
SITE 1																				
Browse	168	1022	1722	1473	745	244	1045	1748	1654	885	248	978	1592	1871	1087	267	812	303	698	1003
Herbage	90	1036	1558	743	184	105	767	2274	942	299	102	680	1914	1152	352	89	518	2536	2431	951
Total	258	2058	3280	2216	929	349	1812	4022	2596	1184	350	1658	3506	3023	1439	356	1330	2839	3129	1954
SITE 2																				
Browse	110	297	877	842	--	196	373	747	908	--	152	273	390	808	--	104	394	144	334	--
Herbage	247	1092	2940	1242	--	164	1163	2850	1098	--	135	450	3299	1847	--	280	790	2398	2265	--
Total	357	1389	3817	2084	--	360	1536	3597	2006	--	287	723	3689	2655	--	384	1184	2542	2599	--
SITE 3																				
Browse	310	2356	1955	1612	1007	339	2007	1737	2098	1429	324	876	497	1823	1765	266	911	524	1267	1405
Herbage	72	561	829	371	96	22	524	1803	1029	254	59	1257	2556	1796	389	43	375	2411	2507	906
Total	382	2917	2784	1983	1103	361	2531	3540	3127	1683	383	2133	3053	3619	2154	309	1286	2935	3774	2311

The dominant herbaceous species were panic grasses and longleaf uniola. Other herbs showing large increases were sedges (*Carex* spp.) and dogfennel (*Eupatorium capillifolium* (Lam.) Small).

On site 2, total forage yield ranged from 723 to 1536 kg/ha, averaging 1208 kg/ha; a threefold increase over the uncut forest. Herbs increased more than browse on this formerly cleared site.

Browse species contributing most to forage yield were American beautyberry, post oak, and sweetgum. Panic grasses were the dominant herbaceous species. Other herbs showing large increases were pinehill bluestem, longleaf uniola and sedges.

On site 3, total forage yields ranged from 1286 to 2917 kg/ha, averaging 2217 kg/ha; a sixfold increase over the uncut forest. Herbs increased proprtionately more than browse plants, and constituted 31 percent of the total forage. Yields of both browse and herbage were relatively low on plots that were to be KG bladed because these plots, unlike the others, carried many leftover culls and small trees throughout the 1973 growing season.

Browse species contributing most to forage yield in 1973 were American beautyberry, blackberries, grapes, willow oak, and sweetgum. Panic grasses replaced longleaf uniola as the dominant herbaceous species. Other herbs showing large increases were sedges, rushes (*Juncus* spp.) and the composites fleabane (*Erigeron* spp.), dogfennel, and wild lettuce (*Lactuca canadensis* L.).

After Site Preparation

Total available forage yield peaked the first growing season following site preparation on the control, burn, and chopped treatments on all three sites (Table 1). The sole exception was the control on site 3 which peaked the year after clearcutting.

By and large on all three sites the total forage yield was similar the first year after site preparation for the control, burn, and chopped plots, but the proportion of browse and herbage varied between sites and site treatments. Sites 1 and 3 generally produced more browse than herbage. The formerly cleared site 2 produced much greater quantities of herbage than browse.

With one exception (KG treatment on site 3) herbage yields peaked the first growing season after site preparation. With gradual closure of the pine canopy and an increase in the height and density of other woody plants, herbage yields decreased. The decrease was faster on treatments that did not reduce the number of woody plants drastically (control and burn). Herbage decline was slow on chopped plots and especially on KG plots where many woody plants were eliminated or greatly reduced in size.

On the chopped plots, available browse increased up to the third growing season but decreased by the fifth. The reason for the third season increase was the recovery of woody plants from the effects of chopping. By the fifth season many woody plants had grown beyond the 1.5 m height limit that is easily accessible to deer (*Odocoileus virginianus*).

On the KG bladed plots total forage yield was greatest in the third growing season. Browse was still increasing by the end of the fifth growing season as woody plants continued to recover from the effects of blading, but herbage yield declined. By the end of the fifth season the average total forage yield was directly proportional to site preparation intensity and ranked: control (1016 kg/ha), burn (1434), chop (1796), and KG (2132 kg/ha).

Pine Survival And Growth

KG blading drastically reduced woody plant numbers and resulted in the highest pine survival on all three sites, being 91, 73, and 97 percent (Table 2). The chopping treatment attained the next highest survival with 83, 64, and 90 percent. Burning produced good survival (85 percent) on site 3 which was burned under very favorable wind and fuel moisture conditions. Survival on sites 1 and 2 was low because the fires did not carry as well and woody plant numbers were not reduced below that on control plots. Pine seedling survival on control plots averaged 57 percent, the lowest of all treatments.

Table 2.--Survival of planted pines after five growing seasons

Location	Site treatments			
	Control	Burn	Chop	KG
	percent			
Site 1	55	63	83	91
Site 2	52	41	64	73
Site 3	63	85	90	97
Mean	57	63	79	87 1/

1/ Values connected by the same line are not statistically different at the 0.05 level of probability.

Generally, seedling survival was poorest on the dry soils of site 2. Survival on sites 1 and 2 that were planted in spring 1975 was not as good as on site 3 which was planted in spring 1974. A rainy growing season followed in 1974 and was in contrast to the hot dry summer of 1975.

The severity of woody plant competition to planted pines is shown by the high percentage of pines that were overtopped by hardwoods and shrubs on the control and burned plots (Table 3). By contrast only few pines were overtopped on chopped plots and even less on KG bladed plots.

Table 3.--Planted pines overtopped by hardwoods

Location	Site treatments			
	Control	Burn	Chop	KG
	percent			
Site 1	43.2	41.2	7.2	0.7
Site 2	14.9	27.2	8.9	0.9
Site 3	32.3	9.0	0.7	1.0
Mean	30.1	25.8	5.6	0.9 1/

1/ Values connected by the same line are not statistically different at the 0.05 level of probability.

Height growth of pines was significantly better on KG bladed and chopped plots than on the control and burned plots (Table 4). Trees that grew tallest also had the greatest diameters (dbh). Several studies showed that the early advantages in growth due to site preparation are maintained for a long period in the life of the young stand, possibly through its entire expected rotation (Wagenknecht 1941, Stransky 1964, Schultz 1975).

Table 4.--Height of planted pines after five growing seasons

Location	Site treatments			
	Control	Burn	Chop	KG
	cm			
Site 1	285	290	355	410
Site 2	299	251	321	331
Site 3	306	305	370	311
Mean	297	282	349	351 1/

1/ Values connected by the same line are not statistically different at the 0.05 level of probability.

Nantucket tipmoth (*Rhyacionia frustrana* Comstock) severely damaged the growing tip of pines on all three sites and could have caused some growth losses. The damage averaged 76, 73, and 74 percent for sites 1, 2, and 3. Both mechanized site treatments showed 69 percent damage, 71 percent on controls, and 89 percent on burned plots. Possibly the initial rate of infestation was the same with all site treatments, but the more vigorous trees on chopped and KG plots appeared to have outgrown the visible signs of tipmoth damage by the fifth growing season.

SUMMARY

Total forage production averaged 345 kg/ha in the uncut timber stands. Differences between site and treatment plots were not significant.

After clearcutting, yields increased several fold. The least increase was on the KG and chopped plots that still supported unmerchantable trees.

Yields peaked the first year after site preparation on all treatments and sites except the KG plots, which peaked the third year.

Five years after site preparation the average forage yields on sites 1 and 3 had declined, but they were still about five times greater than they had been in the uncut forest. The yields were in direct proportion to intensity of site preparation.

On site 2, the area previously cultivated, the browse/herbage proportion was relatively low before and after site preparation. The opposite was true on sites 1 and 3 for the control and burn treatments. On the mechanical treatment plots the browse/herbage ratio was low the first few years after treatment but relatively high the fifth year.

Pine survival, height and diameter growth averaged highest on the KG bladed plots from which most of the non-pine woody vegetation was eliminated, followed by chopping, burning and control.

Continued observations will tell how long the forage production can be maintained by the various site treatments to support wildlife and how much the treatments affect pine tree growth in the long run.

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EFFECTS OF SILVICULTURAL PRACTICES ON BIRDS IN A NORTH FLORIDA FLATWOODS[1/]

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Abstract.--Avian community composition was monitored before and after clearcutting and post-harvest treatments in North Florida flatwoods, Bradford County, Florida from June 1977 to February 1980. Several new species were attracted to cleared areas. A few bird species that overwintered in the flatwoods increased in density on the treatment sites after harvest. Use of the treatment areas after harvest by breeding species was primarily confined to cypress/bay habitats. Practices which may be beneficial to flatwoods avifauna in areas being managed for pulpwood production are leaving cypress/bay habitats intact in areas being harvested, creating windrows in clearcuts, leaving snags standing, and allowing some understory development in plantations.

INTRODUCTION

Since 1952, private forest industry has increased its timberland holdings in Florida by 0.4 million ha (U.S. Department of Agriculture 1978). The majority of this land is in North Florida and is managed for slash pine (Pinus elliottii) production.

The consequences of intensive forest management practices on the indigenous North Florida flatwoods avifauna have been poorly documented. Studies conducted on the effects of forest management practices on avian communities in other areas have shown varying results. Noble and Hamilton (1975) assessed avian community composition in a mature uneven-aged pine-hardwood stand and compared it with 3 stages of even-aged loblolly pine (Pinus taeda) plantations. They observed that from 2 to 10 times more birds inhabited the mature stand than inhabited the even-aged plantations. Conner (1979) found the overall effects of clearcutting mature stands of pine-oak in Virginia to be detrimental to the avian community. These studies generally indicate that avian density and diversity increase as a forest stand matures. However, other studies imply that avian density and diversity reach their peak a few years after clearcutting and diminish as the stand matures. In pine flatwoods of Mississippi, greater numbers of bird species and individuals occurred in younger pine plantations than in the interior of uncut, mature stands (Perkins 1973). Winter densities of birds in different aged pine stands in Texas were greatest in the small sapling stage (Dickson and Segelquist 1977).

Most studies have assessed only the impacts of forestry on overall density and diversity. While avian density and diversity may increase on sites managed for slash pine production, bird species composition may be substantially altered (McArthur and Whitmore 1979). Cleared areas may be more attractive to birds seeking early successional habitats, but be unattractive to avian species specialized for a more mature forest. Therefore, determination of bird species composition in both managed and unmanaged areas is helpful in understanding impacts of forest management practices on indigenous avifauna.

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Objectives of this study were to determine the number of avian species and individuals utilizing a North Florida flatwoods prior to and after harvesting and site preparation and to recommend practices to minimize the possible adverse effects of forest management practices on the native avifauna.

This study was part of a larger investigation that is attempting to determine the effects of forest management practices on an array of forest resources (IMPAC - Intensive Management Practices Assessment Center). IMPAC is an ongoing project sponsored by the U.S. Forest Service. The cooperation of Container Corporation of America, Starke, Florida, in providing study sites and treatments, is gratefully acknowledged.

Study Area

This study was conducted on 3 contiguous, experimental watersheds in Bradford County, approximately 5 km west of Starke, Florida (Figure 1). Prior to its purchase by Container Corporation of America in 1938, Empire Lumber Company owned and managed the land for sawtimber. The tract was cut in about 1950 and regenerated itself naturally (T. Cremer, pers. comm).

Pine flatwoods dominated the regenerated tract, which also was interspersed with cypress (Taxodium distichum) ponds. The canopy of the pine areas was comprised of slash pine and scattered longleaf pines (Pinus palustris). Major understory species in the pine areas were gallberry (Ilex glabra), wax myrtle (Myrica cerifera), and saw palmetto (Serenoa repens). Cypress ponds had variable canopies ranging from a predominance of cypress to a combination of cypress, loblolly bay (Gordonia lasianthus), and blackgum (Nyssa sylvatica). Ponds comprised solely of a cypress overstory typically had a closed canopy and a more open understory. Major understory species in these sites were myrtle-leaved holly (Ilex myrtifolia) and St. Johnswort (Hypericum brachyphyllum). Sites that were comprised of cypress, bay, and blackgum had a more open canopy which allowed for a lush understory of fetterbush (Lyonia lucida) and greenbriar (Smilax spp.).

In November 1978, Watersheds 1 and 2 were harvested (Table 1) and Watershed 3 was left intact to serve as a control. A total of 59 percent of Watershed 1 and 74 percent of Watershed 2 were cut (Riekerk et al. 1980). The cypress/bay areas were left intact during application of harvest and site preparation practices.

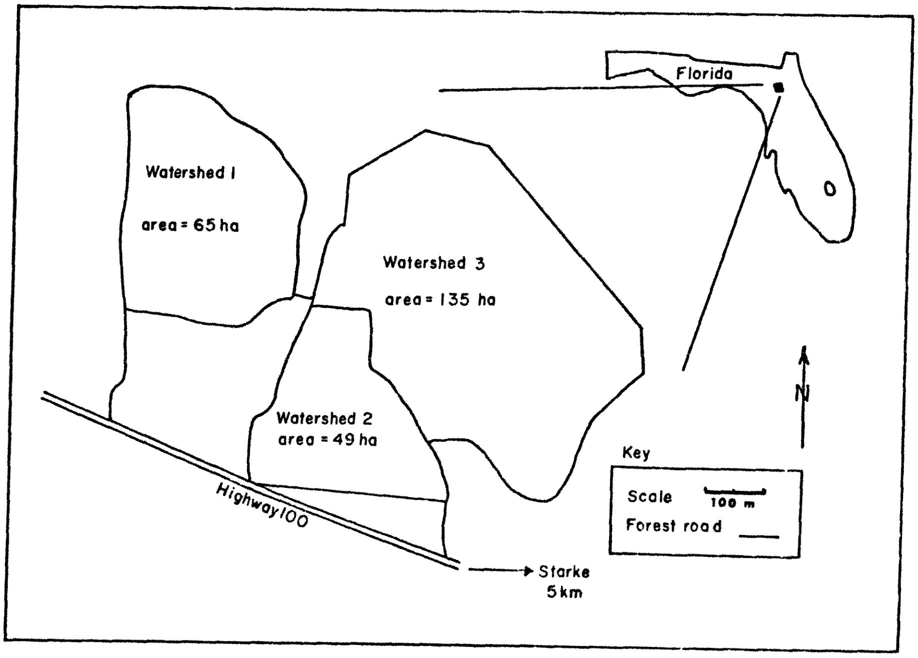

Figure 1.—Map showing location of experimental flatwoods watersheds, Bradford County, Florida.

The minimum treatment site (Watershed 1) retained a substantial amount of understory in the clearcuts. The clearcuts of the more intensively managed area (Watershed 2) were completely devoid of vegetation, except for slash that was pushed into windrows at approximately 50 m intervals after the site was burned.

Methods

Eight transects of lengths varying from 270 to 932 m were established at least 200 m apart in the three watersheds. Approximately 45% of the transect intersected pine and 55% intersected cypress/bay habitats in Watershed 1, 62% intersected pine and 38% intersected cypress/bay habitats in Watershed 2, and 80% intersected pine and 20% intersected cypress/bay habitats in Watershed 3 (the Control).

The transects were traversed 6 to 15 times per season, with the exception of the Autumn of 1978, when Watersheds 1 and 2 were harvested. Data were collected between sunrise and 1200 EST on days with favorable environmental conditions (Sheilds 1979). The order in which the transects were traversed was rotated so that each area would be monitored as often as possible in the early morning hours when birds were most active (Robbins 1978). Seasons were designated as winter (December through February), spring (March through May), summer (June through August), and autumn (September through November). For the purposes of this paper, birds present during the spring and summer constituted the breeding community, whereas those present in the autumn and winter comprised the wintering community.

Birds seen or heard within 10 m of the transect line were recorded and from these data, density (birds/km^2) and diversity were determined. In addition, birds seen or heard from 10 to 100 m from the transect line were recorded to augment the species composition list.

Analyses of variance using a split-plot model (Steel and Torrie 1960) were used to determine differences in density of birds by season and watershed, before and after harvesting. Bird species diversity was determined using the Shannon-Wiener Index (Shannon and Weaver 1949). The index is defined as:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

where: H' = diversity index
s = total number of species
i = species number
p_i = proportion of the community that belongs to the ith species

Table 1.--Forest Treatments applied to flatwoods Watersheds 1 and 2, Bradford County, Florida.

Date	Forestry Practices Applied	
	Watershed 1 (Min. Treatment Area)	Watershed 2 (Max. Treatment Area)
Nov-Dec 1978	Harvest (Shortwood)	Harvest (Shortwood)
Jan-Feb 1979	--	Lightwood Stump Removal
April 1979	Chop	--
May 1979	--	Burn
June 1979	--	Windrow (KG-Blade)
August 1979	Chop	Harrow
Sept-Oct 1979	Bed	Bed
November 1979	Plant (Mechanical)	Plant (Mechanical)

Minimum diversity ($H' = 0$) is attained when only one species is present. Maximum diversity ($H' = \ln s$) is achieved when all individuals are equally apportioned among the species present.

Data collected on the watersheds from June 1977 to August 1978 were considered to be baseline information. When referring to trends in the treatment watersheds after harvest, it should be noted that the number of species, density, and diversity were determined from data collected in intact cypress/bay habitats as well as cleared areas. Most tracts that are harvested in the North Florida flatwoods contain cypress/bay areas that are left intact. Homogeneous clearcuts probably would not exhibit similar population trends.

Results and Discussion

Overall density of birds in the less intensively managed tract (Watershed 1) increased in all seasons after harvest (Figure 2). This tract retained substantial cypress/bay habitat after the harvest. The increase in avian density was apparently due to retention of flatwoods species in the intact cypress/bay habitats and the addition of species attracted to the clearings. Also ,edges created between cypress/bay areas and clearcuts may have contributed to higher bird densities on Watershed 1. McElveen (1978) found breeding bird densities were greater in edges between cypress/bay areas and clearcuts than in cypress/bay and pine ecotones in North Florida flatwoods.

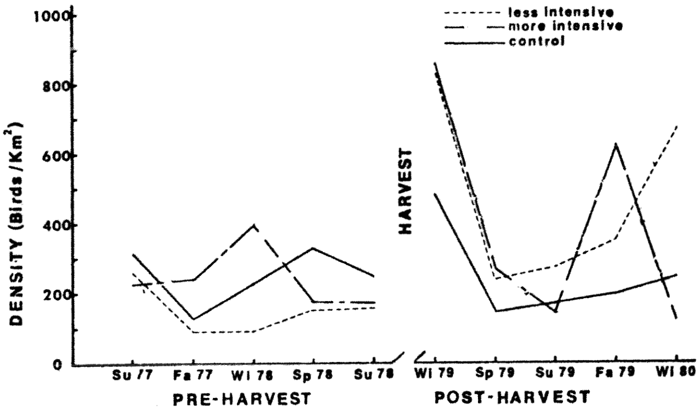

Figure 2.--Seasonal variation in density (birds/km^2) on the 3 study areas before and after harvest in Bradford Forest, Bradford County, Florida, June 1977 - February 1980.

No obvious trends existed in overall avian density for Watershed 2 (Figure 2) or for bird species diversity (Figure 3) and number of species (Figure 4) for both Watersheds 1 and 2.

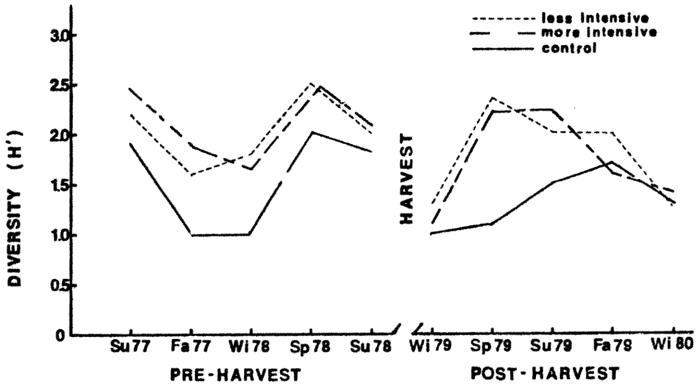

Figure 3.--Seasonal variation in diversity (H') on the 3 study areas before and after harvest in Bradford Forest, Bradford County, Florida, June 1977 - February 1980.

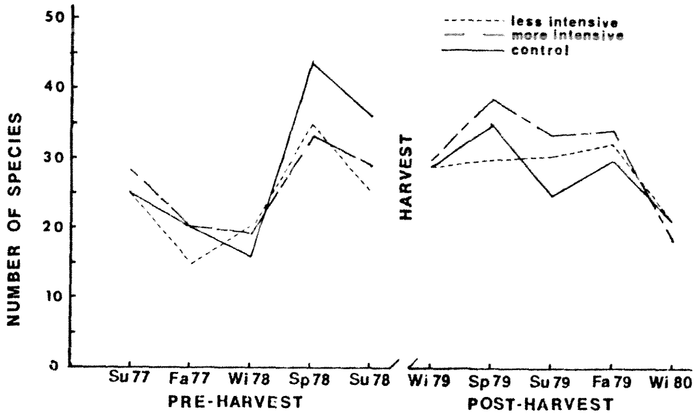

Figure 4.--Seasonal variation in number of species on the 3 study areas before and after harvest in Bradford Forest, Bradford County, Florida, June 1977 - February 1980.

Analyses of variance showed no significant differences in pre-harvest data within or between seasons. After harvest, the winter of 1979 had significantly greater avian densities than the other seasons ($P < 0.05$, LS Means Test). However, bird density in the treatment areas did not differ significantly from the control in the winter of 1979. The increase in densities was apparently due to normal population fluctuations rather than the silvicultural treatments.

Overall, the control area had a high number of species, density, and diversity in the spring and summer just prior to harvest. Avian composition may have been affected by the construction of a powerline corridor through the site in the autumn of 1977 and the winter of 1978. Borrow pits dug along the side of the corridor in the winter of 1978 were periodically inundated with water, attracting several species of wading birds to the site in the spring and summer of 1978(Table 2). As vegetation regenerated along the corridor, it became less attractive to these species, resulting in a lower number of species, density, and diversity the following spring and summer. The powerline corridor also bisected Watershed 2, but we were unable to segregate responses of birds to powerline construction from those associated with on-site silvicultural practices.

As understory vegetation began to regenerate, several bird species began to utilize the cleared areas in both Watersheds 1 and 2. These species included the American kestrel (*Falco sparverius*), killdeer (*Charadrius vociferus*), common snipe (*Capella gallinago*), ground dove (*Columbina passerina*), red-headed woodpecker (*Melanerpes erythrocephalus*), eastern phoebe (*Sayornis phoebe*), loggerhead shrike (*Lanius ludovicianus*), eastern meadowlark (*Sturnella magna*), and red-winged blackbird(*Agelaius phoeniceus*).

The creation of windrows apparently further attracted avian species to Watershed 2. House wrens (*Troglodytes aeden*), mockingbirds (*Mimus polyglottos*), and eastern bluebirds (*Sialia sialis*) were commonly seen utilizing the windrows.

Densities of several indigenous flatwoods avian species increased on the harvested tracts. Large flocks of American robins (*Turdus migratorius*) and mourning doves (*Zenaida macroura*) were observed feeding in the cleared areas of Watershed 2. The reduction of ground vegetation and litter in this area probably exposed some forage items that otherwise would not have been available (Wood and Niles 1978). Thick stands of grass that regenerated along the southern edge of Watershed 2 attracted white-throated (*Zonotrichia albicollis*) and swamp sparrows (*Melospiza georgiana*), resulting in increased densities of these birds in this area (Table 2). Finally, the interface between the clearcuts and cypress/bay habitats in Watershed 1 attracted large flocks of yellow-rumped warblers (*Dendroica coronata*), palm warblers (*Dendroica palmarum*), and red-winged blackbirds, increasing the density of these species in Watershed 1 (Table 2).

Most of the species that made use of the clearcuts were open land species previously unrecorded in the area, or indigenous flatwoods birds that overwintered in the area. Very few birds were observed in the clearcuts during the breeding season. Eastern meadowlarks were heard singing in the clearcuts of Watershed 1 in the summer of 1979. Bachman's sparrows were heard

Table 2.--Density (birds/km^2) of 89 bird species recorded in Watershed 1 (less intensive practices), Watershed 2 (more intensive practices), and Watershed 3 (nondisturbed) in Bradford County, Florida, June 1977 - February 1980.

Species 1/	Seasonal Status 2/	PRE-HARVEST												POST-HARVEST																	
		Summer 77			Autumn 77			Winter 78			Spring 78			Summer 78			Winter 79			Spring 79			Summer 79			Autumn 79			Winter 80		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Wood Duck (*Aix sponsa*)	R											X 3/												X							
Common Egret (*Casmerodius albus*)	R							X								X					X						X				
Cattle Egret (*Bubulcus ibis*)															X	X															
Little Blue Heron (*Florida caerulea*)	R												X		X	X		X	X		4	X		8	X						
Green Heron (*Butorides virescens*)	R										6			X		5															
Black Vulture (*Coragyps atratus*)	R	X									X		X	X						6											
Turkey Vulture (*Cathartes aura*)	R		X								X		X						X											X	
Cooper's Hawk (*Accipiter cooperii*)	R												X																		
Sharp-Shinned Hawk (*Accipiter striatus*)	W										5																				
Red-Tailed Hawk (*Buteo jamaicensis*)	R												X																		
Red-Shouldered Hawk (*Buteo lineatus*)	R							X			X		22	X							X		X	X			X				X
American Kestrel (*Falco sparverius*,	R																									9	X		X		
Bobwhite (*Colinus virginianus*)	R	X	6	13		55			/8	150	13	11	145	16	10	X		116				3	22	17	X						
Killdeer (*Charadrius vociferus*)	R																										X				
Spotted Sandpiper (*Actitis macularia*)	T											X	26		X																
Common Snipe (*Capella gallinago*)	W										X															X					
Mourning Dove (*Zenaida macroura*)	R	X	10	X		X					X		13	11	41	X		X	X	X	7	X	X	4	X	X	78	X	X	X	X
Ground Dove (*Columbina passerina*)	R																				X			8							
Yellow-Billed Cuckoo (*Coccyzus americanus*)	S		X								X	6			X								X	X							
Great Horned Owl (*Bubo virginianus*)	R			X																		X									
Screech Owl (*Otus asio*)	R																			X											
Chuck-Will's Widow (*Caprimulgus carolinensis*)	S												93			17						13									
Common Nighthawk (*Chordeiles minor*)	S												X		8	X							X	X							
Ruby-Throated Hummingbird (*Archilochus colubris*)	S												X											12							
Belted Kingfisher (*Megaceryle alycon*)	W					X										5				X	X						X				
Common Flicker (*Colaptes auratus*)	R	X	6	X								X				37	X	X	X	X			7			X	16	X		22	X
Pileated Woodpecker (*Dryocopus pileatus*)	R	8	6	X						X	X	6	X	X		X				X	X	X	14	X	X	9		X	X		
Red-Bellied Woodpecker (*Melanerpes carolinus*)	R	21	12	X	19	X	X	6	X	X	X	16	X	23	13	16	20	8	11	12	18	X	7	4	8	4	22	X	X	22	X
Red-Headed Woodpecker (*Melanerpes erythrocephalus*)	R																				X		7								
Yellow-Bellied Sapsucker (*Sphrapicus varius*)	W						X	6		X							X	X	3		X	X					11	X			X
Hairy Woodpecker (*Picoides villosus*)	R		12			X						7																			
Downy Woodpecker (*Picoides pubescens*)	R	X	X	10		X			10		X		X	5	X	20		X	X		3		13	8	7	9	22	3			
Great Crested Flycatcher (*Myiarchus crinitus*)	S	14	12	59							5	9	14	6	19	11				6	21	8	3	25	7						
Eastern Phoebe (*Sayornis phoebe*)	W																13	X								9	X			22	
Eastern Wood Pewee (*Contopus virens*)	S											X																			
Tree Swallow (*Iridoprocne bicolor*)	W																									X	X				
Blue Jay (*Cyanocitta cristata*)	R	4	19	17		X	X				X	20	14	5	X	X	X	X		3	22	14	X	X	10	X	5	X	X	X	
Common Crow (*Corvus brachyrhynchos*)	R		X				X		X			X				X	X	X	8			X		X	X	X	10	X			X

1/ Scientific names from Check-list of North American Birds (American Ornithologists' Union 1957) and its supplements (American Ornithologists' Union 1973, 1976).

2/ Seasonal status determined from a local check-list (Austin 1975), R = resident, W = winter resident, S = summer resident, T = transient.

3/ X denotes bird was present on the site, but was not observed on the transects being monitored for density estimates.

Table 2, cont'd.

Species[1]	Seasonal Status[2]	PRE-HARVEST															POST-HARVEST														
		Summer 77			Autumn 77			Winter 78			Spring 78			Summer 78			Winter 79			Spring 79			Summer 79			Autumn 79			Winter 80		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Fish Crow (Corvus ossifragus)	R		X								X		X							X	7	X	X	8							
Carolina Chickadee (Parus carolinensis)	R	5	12	33	X	22	39	30	X		X	X	13	X	14	31	7	4	X	12	X	X	7		4		11	10	X		X
Tufted Titmouse (Parus bicolor)	R	X	12	43	X	21	19	X	16	49	5	7	27	6	8	74	X		17	X	4	3	X	X	5	X	X	14	X	X	X
Brown-headed Nuthatch (Sitta pusilla)	R	X	10	14	X		X	X			X	X	X	22	14	35	7	X	8	3	X	3	X	X	4	X		X			
House Wren (Troglodytes aedon)	W																X	8	X	X	14	6				X	6	X		X	X
Carolina Wren (Thryothorus ludovicianus)	R	36	39	46	30	16	30	29	28	20	9	7	24	59	33	29	32	12	4	16	29	17	52	33	22	28	11	19	19	34	23
Mockingbird (Mimus polyglottos)	R														X	5	7	X			7					22	39		18	X	
Gray Catbird (Dumetella carolinensis)	W				10	X	X	16	X		15	6	14		X		46	8	X	54	X	X				52		7	19		30
Brown Thrasher (Toxostoma rufum)	R	4	12	9	X		20			X	5		X	5		37				X			22	X	X	5	X				
American Robin (Turdus migratorius)	W					52	X	12	173	140			X				373	587	251							22	145		153	11	127
Hermit Thrush (Catharus guttata)	W																	X													30
Swainson's Thrush (Catharus ustulata)	T					22		6																							
Eastern Bluebird (Sialia sialis)	R										X			X			X				X		7	4		90	10			X	
Blue-Gray Gnatcatcher (Polioptila caerulea)	R	23	14	23							9	15	20	6	X	X				9	19	3	10	8	10		22	10			
Ruby-Crowned Kinglet (Regulus calendula)	W							X	38	18	6	7	12				21	4	21	6	7	20				14	6	7	9	X	7
Cedar Waxwing (Bombycilla cedrorum)	W																X		X	96	X	41									
Loggerhead Shrike (Lanius ludovicianus)	R																							8		X	11				
Solitary Vireo (Vireo solitarius)	W				X	X		X		X			14						X			X							18		
White-Eyed Vireo (Vireo griseus)	R	6	6	24	29	44	20	12	X	73	6	13	26	6	7	X	X		X	13		10	14	X	14	9		17	9		X
Yellow-Throated Vireo (Vireo flavifrons)	S										X		X											X							
Red-Eyed Vireo (Vireo olivaceus)	S															X															
Black-and White Warbler (Mniotilta varia)	W					X	20	6	8	11	12		X				7	X	79	X	7	X				10		10	X		X
Prothonotary Warbler (Protonotaria citrea)	S	17	X	X							5	X		11	X								7	8							
Northern Parula Warbler (Parula americana)	S	X	6	16	X		X				6	7	22	17	21	15				16	7	3	7	X	X			X			
Cape May Warbler (Dendroica tigrina)	T										X		X																		
Yellow-Rumped Warbler (Dendroica coronata)	W				X	X	19	X	105	130		20	67				337	192	153	X	100	10				X	235	27	214	11	
Black-Throated Blue Warbler (Dendroica caerulescens)	T																					X									
Yellow-Throated Warbler (Dendroica dominica)	S	17		X							X	X	X		X					X	7	X			X						
Blackpoll Warbler (Dendroica striata)	T											X																			
Pine Warbler (Dendroica pinus)	R	14	29	27	X	22	50	7	19	14	21	15	50	5	X	49	13	4	9	X	3	5	10	8	27	4	6	42			23
Prairie Warbler (Dendroica discolor)	T	4	10												7	17															
Palm Warbler (Dendroica palmarum)	W												14				7	X								104	21				
Ovenbird (Seirus aurocapillus)	W											6																			
Common Yellowthroat (Geothlypis trichas)	R	50	30	21	15	22	28	16	26	19	24	30	14	11	28	45	14	X	9	9	X	19	66	4	28	23	22	24	9	22	62
American Redstart (Setophaga ruticilla)	T						X					7				15				12		X				5		13			
Eastern Meadowlark (Sturnella magna)	R																						X				X		X		
Red-Winged Blackbird (Agelaius phoeniceus)	R																				X						X		573		
Boat-tailed Grackle (Quiscalus mexicanus)	R												X																		
Common Grackle (Quiscalus quiscula)	R											X	11			X					15		74	8	X						
Summer Tanager (Piranga rubra)	S	X	X	X								X	X	X		X						X			7			20			
Cardinal (Cardinalis cardinalis)	R	10	35	8	10	11	41	6			19	6	12	6	X	74	13	X	17	6		27	11	X	7	5	22	X			13
Rose-Breasted Grosbeak (Pheucticus ludovicianus)	T																				7										
Indigo Bunting (Passerina cyanea)	S															X															
American Goldfinch (Carduelis tristis)	W												X															19			
Rufous-Sided Towhee (Pipilo Erthrophalmus)	R	64	16	87	20	21	40	14	22	X	17	40	67	25	29	57	25	X	17	15	7	38	21	25	57	23		45	X	22	26
Bachman's Sparrow (Aimophila aestivalis)	R			X																	X		3								
Chipping Sparrow (Spizella passerina)	W																											18	X		
Field Sparrow (Spizella pusilla)	W							X	240																						
White-Throated Sparrow (Zonotrichia albicollis)	W								29		13		14					8			21										X
Swamp Sparrow (Melospiza georgiana)	W											X					X	39	X					7		9	X	X		X	
Song Sparrow (Melospiza melodia)	W							10																						10	

1/ Scientific names from Check-list of North American Birds (American Ornithologists' Union 1957) and its supplements (American Ornithologists' Union 1973, 1976).

2/ Seasonal status determined from a local check-list (Austin 1975), R = resident, W = winter resident, S = summer resident, T = transient.

3/ X denotes bird was present on the site, but was not observed on the transects being monitored for density estimates.

singing in the clearcuts and along the cypress/bay/clearcut interface in both harvested tracts in the spring and summer of 1979. On occasion, Carolina wrens (Thryothorus ludovicianus) and rufous-sided towhees (Pipilo erythropthalmus) were observed singing in the windrows in Watershed 2. However, while most of the breeding indigenous flatwoods bird species still occurred in Watersheds 1 and 2 after harvest, they resided primarily in the intact cypress/bay habitats. Most of the bird species that breed in the flatwoods associate with the understory or are generalists that will breed in the canopy of more than one forest type. The brown-headed nuthatch (Sitta pusilla) and the pine warbler (Dendroica pinus) are the only two species specifically adapted to breed in the canopy of the southeastern flatwoods (Johnston and Odum 1956). Cavity nesters comprised 29 percent of the breeding species in the study area prior to harvest (Rowse 1980). Approximately half of the cavity nesting species in the area are primary (excavate their own cavity) cavity nesters. Since primary cavity nesters usually excavate their holes in dead trees, snags are an important feature of the forest to the indigenous cavity nester (Conner 1978). The most common breeding species of the flatwoods, Carolina wrens, common yellowthroats (Geothylpis trichas), and rufous-sided towhees, breed in the understory.

When avian species select a habitat type, they seek conditions that will best enable them to fulfill their needs for survival and reproduction including a certain type of landscape and terrain, an ample food source, and adequate nesting, singing, and drinking sites (Hilden 1965). It has been well documented that different species are attracted to certain features of the landscape and terrain unique to their needs (James 1971, Shugart and Patten 1972). Even though breeding species did not decrease on the treatment sites after harvest (Table 2), they occurred primarily in the intact cypress/bay habitats and made little use of the clearcut areas. Therefore, breeding indigenous flatwoods birds could only satisfy their habitat requirements in the intact cypress/bay areas of the harvested tracts.

There will always be trade-offs between managing an area for economic gains and managing it for wildlife habitat, but if it is in the interest of forest industry to manage an area to include a variety of resource values, the following recommendations are applicable:

1) Continue to maintain cypress/bay habitat in harvested tracts. These areas serve as a refuge for indigenous flatwoods avian species that could potentially repopulate adjacent plantation areas as they mature.

2) Leave snags standing wherever possible. These trees provide special habitat requirements for cavity nesting species, in addition to serving as perch sites for hawks and owls, and as food sources for many types of passerine birds.

3) Allow some development of understory vegetation in plantations. Many of the indigenous avifauna of the flatwoods use the understory for breeding and feeding.

4) Push slash into windrows. Windrows add heterogeneity to clearcuts and provide food and cover for some of the flatwoods species as well as open land species that may be attracted to the site.

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RE-ESTABLISHING YELLOW PINE HABITAT FOR THE RED COCKADED WOODPECKER ON THE CUMBERLAND PLATEAU[1]

J. Daniel Thomas and Edward Buckner[2]

Abstract.--Developing inexpensive silvicultural systems for increasing the pine component of forests on the Cumberland Plateau is essential for maintaining a population of red cockaded woodpeckers in that area. Site preparation and hardwood control techniques considered feasible and acceptable on the Catoosa Wildlife Management Area were tested; these included: (1) burning, (2) fire plowing, (3) drum chopping, and (4) a velpar treatment. Both direct seeding and planting were tested for establishing shortleaf pine, and deer exclosures were constructed to determine the influence of deer browsing on stand composition.

First year survival was best in the fireplowed rows for both direct seeding and planted seedlings. However, total height was greatest for planted seedlings in the drum-chopped area. Burning had no significant effect.

The effectiveness of the hardwood control treatments was evaluated by recording for each planting "spot" the likelihood that an established pine seedling (whether present or not) would outgrow hardwood competition. Both fire plowing and drum chopping significantly reduced hardwood competition.

INTRODUCTION

Once common in the southeast, the red cockaded woodpecker (Picoides borealis) is currently listed as an endangered species, primarily due to loss of suitable habitat (Jackson et al, 1979).

A remnant population (2-3 pairs) still remains on a marginal habitat on the Catoosa Wildlife Management Area (CWMA) on the Cumberland Plateau in Tennessee. This is the only population on public lands in the State where management goals will allow restoration of the habitat. The single most important habitat requirement is a mature or decadent stand of yellow pine for nesting.

Natural succession in this region is to hardwoods and the few remaining old pine stands are being replaced with hardwoods. Silvicultural systems used on the CWMA are not intensive and generally result in release of hardwood competition, further reducing the pine acreage.

The intensive site preparation methods used by industry are neither economically feasible nor compatible with management objectives for the area. Developing inexpensive silvicultural systems for favoring pine is essential for maintaining a population of red cockaded woodpeckers on the CWMA (the largest - 80,000 acres - wildlife management unit in Tennessee).

Attempts over the last several years to manipulate habitats to favor the red cockaded woodpecker on the CWMA have been unsuccessful. Historical accounts indicate that fire played a key role in the establishment of the remnant pine stands that provide their present habitat.

This study was designed to test economically feasible silvicultural systems for increasing the pine component on the CWMA.

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[1] Funded thru the endangered species fund by U. S. Fish and Wildlife Service and the Tennessee Wildlife Resources Agency.

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METHODS

Study Area. The study locations were on a broad ridge in an area designated for management as red cockaded woodpecker habitat. Two study plots (900' x 900' = 18.4 acres each) were established where soils and forest cover appeared uniform.

To simulate conditions following logging (an activity that will usually precede any effort to convert to pine), hardwoods larger than 3" diameter were removed and/or poisoned (a stipulation in all logging contracts on the CWMA).

The original forest cover was characterized through four sample plots in an adjacent area that was not disturbed. Trees greater than 11 inches d.b.h. were tallied on 1/5 acre plots; concentric plots of 1/20, 1/40, and 1/100-acres were established on which, respectively, pulpwood (3 inches to 11 inches d.b.h.), saplings (6' tall to 3 inches d.b.h.), and regeneration (trees less than 6 feet tall) were measured.

Treatments tested for establishing shortleaf pine (Pinus echinata Mill.) were:

A) Site preparation to control competing vegetation.

  1. Burn types:

    a) spring burn
    b) summer burn
    c) both spring and summer burns
    d) control

  2. Mechanical treatments:

    a) fire plowing
    b) drum chopping
    c) control

  3. A velpar "gridball" application

B) Planting methods

  1. direct seeding

  2. planting seedlings

C) Deer exclosure (to determine the influence of deer browsing on the establishment and growth of shortleaf pine and on the unwanted hardwood competition.)

The large study plots were divided into four equal subplots for testing the burn and control treatments. Summer burning was done in July 1978 and spring burning in March, 1979. One subplot in each area was burned on both dates (Figure 1).

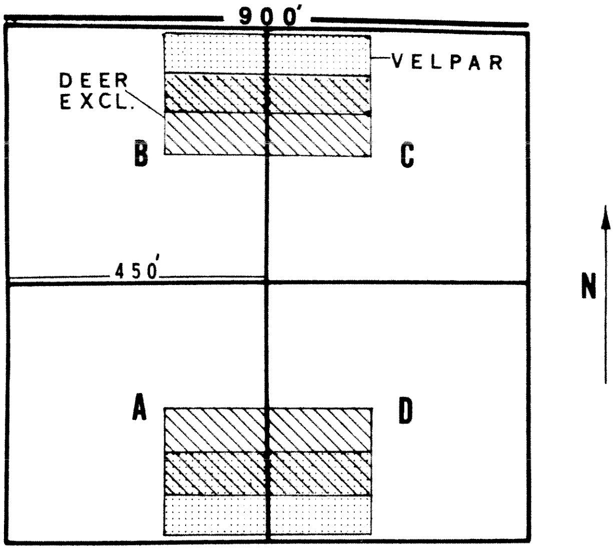

Figure 1. Arrangement of burn treatments, deer exclosures, and velpar treatments.

Two methods of mechanical site preparation were tested against a control in each of the 4 main treatment plots. A split block arrangement was used in which fire plow and drum chopper rows (15 feet wide) ran in a north-south direction the entire length of the study plots. These mechanical treatment sub-units consisted of the random assignment of the 3 treatments (applied to the 15 foot strips) to the 45-foot wide mechanical treatment unit (See Figure 1). Soil samples (40 at each location) were taken, half from the bottom of the fireplow trench and the other half from undisturbed soil.

Regeneration methods were tested by alternating between direct seeding in one mechanically prepared unit to planting 1-0 seedlings in the next unit. Seedlings were from the Tennessee Division of Forestry nursery in Pinson, Tennessee; the seeds used in direct seeding were obtained from the Division of Forestry, Fisheries and Wildlife, Tennessee Valley Authority, and were from southeastern Kentucky (source 64, lot 2). The germination percentage for these seeds was approximately 80 percent.

Plantings were at 7 foot intervals in rows that were 15 feet apart; planting rows were centered in the mechanically prepared strip. Seeds were treated with bird and rodent repellent prior to direct seeding. Plastic flagging was used to mark the direct seeding locations, which were scarified prior to placing 1-3 seeds at each point of a triangular arrangement having approximately 1-foot sides.

Following planting, Velpar "gridballs" were placed on a 6' x 6' grid. Approximately 1.25 acres were treated at each location to give equal portions of all treatments (Figure 1). The size of both the deer exclosures (375 ft. x 145 ft) and the Velpar treatments were dictated by the requirement that at least 2 replications of each mechanical treatment and planting method be included in each of the burn types.

Construction delays resulted in deer exclosures not being operational the first growing season, therefore negating any further inferences at this time.

Survival, height, and hardwood encroachment on planting positions were measured in the spring of 1980, one year after planting, residual hardwood competition at each planting position was measured on a scale of increasing competition where 1 represented no competition to 5 representing complete over topping that will likely result in the death of an established pine seedling. These measurements were made after hardwoods were in full leaf to accurately judge the degree of competition.

RESULTS AND DISCUSSION

Differences between the two study areas that became apparent during the inventory include: (1) the south area had more large residual pines (not removed since conversion was to pine), (2) there was a dense ground cover of grass on the south area.

Dispite greater competition from large pines and grass, hardwood competition was greater in the south area (3.3) than in the north (2.9) (Table 1). More seedlings were established from direct seeding on the north area, probably due to less grass and hardwood competition. Survival of planted seedlings was approximately equal for the two areas, as was their total height.

Treatments. The three burn types had no significant effect on any of the parameters measured.

Among mechanical treatments, planting in fireplow trenches resulted in much higher survival, both for tree planting and direct seeding (70 and 74 percent respectively, compared to 50 and 27 percent for the other mechanical treatment). These greatly improved survival and establishment percentages for planted seedlings and direct seeding can probably be attributed to decreased root competition and greater available soil moisture in the fireplow trench; exposing mineral soil provided a further establishment advantage for direct seeding.

Survival and establishment were not significantly improved by drum chopping; however, the height of planted seedlings was 9 percent greater ($P \geq 0.05$) (Table 1). This gain over control likely resulted from reduced hardwood competition. The absence of a height-growth response to reduced competition in the fireplow rows can be attributed to poor physical and chemical soil properties (P and K were significantly lower - $P \geq 0.05$ - in fireplow rows).

Table 1. Least squares means for treatment effects on the two areas. An asterisk indicates mean(s) significantly different at the 0.05 level.

AREAS AND TREATMENTS	Hardwood Competition[1]	Total Height (Seedlings) inches	Survival (Seedlings) percent	Establishment (Seeds) percent
AREA				
North	2.9	13.9	55	44
South	3.3*	14.2*	57	38*
MECHANICAL TREATMENT				
None	3.7*	13.7	49	21
Fireplow	2.8	13.7	70*	74*
Drum Chop	2.9	14.9*	50	27
VELPAR GRIDBALLS				
Untreated	3.3	13.6	56	38
Treated	2.9*	14.5*	57	43*

In velpar-treated plots: (1) hardwood competition was reduced, (2) the height growth of planted seedlings was greater, and (3) establishment from direct seeding was greater ($P \geq 0.05$ for all). The 12 percent reduction in residual hardwood competition probably accounts for the 7 percent increase in the height of planted seedlings and a 13 percent increase in establishment from direct seeding, suggesting that velpar had a positive effect in establishing pine.

SUMMARY AND CONCLUSIONS

These preliminary results indicate that the pine component of forest stands on the CWMA can be increased using equipment and systems that are feasible under guidelines established by the Tennessee Wildlife Resources Agency[3].

While burning is convenient and inexpensive and is commonly used on the CWMA, it was not effective as used in this study. Williamson (1964) found that controlled burning of oak-pine stands on the Cumberland Plateau decreased

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[3] Personal communication.

the height of the hardwood understory but increased the number of stems making it almost impossible to regenerate shortleaf pine. However, since burning conditions on both dates used in this study were less than favorable, further investigation is suggested.

Although mechanical treatments are more expensive than burning, those tested appear to be more effective for establishing pine on the Cumberland Plateau. Planting in fireplow trenches resulted in over 70 percent establishment with both tree planting and direct seeding, while establishment in other treatments was 50 percent or less. This establishment gain offsets the small height growth advantage of planted seedlings in the drum chopped plots, a condition that may change when roots grow into the undisturbed soil outside the zone affected by fireplowing. Disadvantages of parallel fireplow rows 15 feet apart is the soil-site disturbance and reduced aesthetic quality for most users of the area.

Fireplowing, drum chopping and velpar apparently reduced hardwood competition for established pine seedlings and drum chopping and velpar appeared to improve growth.

These results suggest that mechanical treatments sufficient to expose mineral soil are needed to adequately establish pine but the best growth will result if soil disturbance is minimal. Hardwood competition indices below 3.0 are probably needed to get established pine into the overstory; both chemical and mechanical site preparation methods accomplished this (Table 1).

Further tests should be made to identify site preparation techniques less drastic than fireplowing that will enable the establishment of pine and reduce hardwood competition.

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FOREST STAND SIMULATION MODEL FOR THE CATOOSA WILDLIFE MANAGEMENT AREA (FORCAT)[1]

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Abstract.--The assumptions and implementation of a forest stand model are presented. The model simulates the dynamics of up to 700 individual trees on a small circular plot. Preliminary results from the application of the model to an upland forest are presented.

INTRODUCTION

Forestry and wildlife managers are often confronted with conflicting demands for resource utilization. The conflicts may be temporal, spatial, or some combination of both. Immediate and intensive management versus long term and sustained yield harvesting of timber may result in a temporal conflict. Concurrent use of an area for wildlife management and timber harvest may create a spatial conflict. As the temporal and spatial scales increase, the formulation of satisfactory management strategies becomes increasingly difficult. Simulation models are one possible aid to decision makers. Models can assist the resource manager in assessing the impact of different management strategies in such areas as resource harvest and regeneration. The development of a forest stand simulation model for the Catoosa Wildlife Management Area (FORCAT) is described. One intended use of this model will be to investigate the interrelationship of deer browsing and forest stand development following cutting.

APPROACH

Shugart and West (1980) have categorized forest simulation models into three groups: individual tree models, gap models, and whole stand models. Individual tree models consider the growth of single trees. Such models are often used to simulate development of managed, commercial forests. Gap models simulate individual trees on a small spatial scale. Models of this type are generally used to investigate ecological succession. Whole stand models consider the dynamics of a large forest or stand. Generally, these models do not consider the dynamics of individual trees.

The model described here is patterned after the gap models of Shugart and West (1977) and Botkin, et al. (1972). These models consider the dynamics of up to 700 trees on a small circular plot. The models utilize the silvicultural characteristics of each species on the plot to control the growth and development of individual trees. Monthly temperature and precipitation on the plot are used as the forcing environmental factors. The models assume that many of the factors influencing plot development are stochastic in both frequency and magnitude. Consequently, these models must be run a number of times and the results averaged.

A gap model was chosen for three major reasons. First, the size of the openings created by the proposed tree harvesting strategy on Catoosa is fairly small. A model which was capable of considering the regeneration dynamics of individual trees following harvest was considered important. Secondly, the impact of deer browsing on a tree is generally a function of the tree height. The taller a tree is, the less severe is the impact of deer browsing. The gap model of Shugart and West (1977) generate the height and foliage

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[1] Paper presented at Southern Silvicultural Research Conference, Atlanta, GA, November 6-7,1980.

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profile of each individual on the simulated plot. This information can serve as input to a deer population model such as ONEPOP[5]. Lastly, the long term consequences of deer browsing on forest development can be investigated with gap models.

The interface between the gap model and a deer population model is not discussed in this paper. Our first concern was to develop a model capable of simulating the long term dynamics of a forest on Catoosa. The impact of herbivory is currently modeled by classifying each tree species as either preferred or non-preferred food. If a species is a preferred food for wildlife, the seeding and sprouting rates for that species are reduced. Eventually, we hope to create more refined palatability indices for the tree species. These indices along with the amount of vegetation of each species on the plot will be input to a deer population model which will allow more detailed simulation of the impact of herbivores.

DESCRIPTION OF THE FORCAT MODEL

FORCAT simulates the growth of each tree on a 1/12 ha circular plot. Tree growth is modeled as a function of present tree size, climate, shading, and crowding from other trees. As in FORET (Shugart and West, 1977), tree growth under optimal conditions is calculated by

$$\frac{Dv(t)}{dt} = \frac{d(D(t)^2 H(t))}{dt} = (R)(LA(t))\frac{(1-D(t)H(t))}{D_{max}H_{max}}$$

where $V(t)$, $D(t)$, $H(t)$, and $LA(t)$ are the volume, diameter at breast height, height and leaf area, respectively, of a tree at time t. R, D_{max}, and H_{max} are the species specific growth rate, maximum diameter, and maximum height, respectively. This equation considers the tree to be a cylinder with the change in tree volume proportional to the amount of surface area available for photosynthesis multiplied by a maintenance factor for the biomass present (Botkin, et al., 1972).

Tree height, $H(t)$, is assumed to be a quadratic function of diameter at breast height, $D(t)$ (Ker and Smith, 1955)

$$H(t) = 137 + b_2 D(t) - b_3 D(t)^2$$

b_2 and b_3 are species specific parameters and are calculated by assuming that $H(t) = H_{max}$ and $dH(t)/dD(t) = 0$ when $D(t) = D_{max}$. Maximum recorded height and diameter at breast height for each species are used as values for H_{max} and D_{max}.

Leaf area, $LA(t)$, is calculated from the empirical relationship (Sollins et al., 1973)

$$LA(t) = (0.1193)\ (D(t))^{2.939}$$

FORCAT decreases the optimum growth of a tree by factors to reflect the impact of shading, climate, competition, and herbivory. Available light for a given tree is modeled as an inverse exponential function of the leaf area above the tree. Two different equations, one for shade tolerant species and one for shade intolerant species, are used to relate available light to a photosynthetic rate factor, $r(AL)$. The value of $r(AL)$ can range from 0 representing poor light conditions to 1 which represents optimal light. The optimal growth equation is multiplied by $r(AL)$ to incorporate the effects of shading tree growth.

Climatic influences on tree growth are of two types: temperature effects and moisture effects. The model assumes that each species has an optimal temperature for photosynthesis and that net photosynthesis decreases symmetrically as temperatures vary from this optimum. Growing degree days above a 42° F base for the site is used to calculate a temperature factor, T(DEGD), as follows

$$T(DEGD) = \frac{4(DEGD - DMIN)\ (DMAX - DEGD)}{(DMAX - DMIN)^2}$$

This function is a parabola with a maximum value of 1 at (DMAX + DMIN)/2 and a minimum value of 0 at DMIN and DMAX. The parameters DMAX and DMIN are species specific values taken to be the extremes of growing degree-days, DEGD, within the species range. The optimal growth equation is multiplied by T(DEGD) to incorporate the effect of temperature.

Decrease in tree growth as a result of moisture stress is modeled as the ratio between a species specific drought tolerance and the number of dry days on the site. Site dry days (DD) is defined as the number of days during the growing season on which the soil water was below wilting point. The field capacity and wilting point are site specific parameters. The model calculates monthly precipitation based on monthly means and variances for the site. Evapotranspiration based on the Thronthwaite equation is used to model loss of soil water. The species-specific drought tolerances are based on the extremes of moisture conditions within the species' range.

The final growth reducing effect considered in the model is related to increased biomass on the stand. This factor is calculated as

$$S(BAR) = 1 - \frac{BAR}{SOILQ}$$

where BAR is the total biomass on the plot and SOILQ is the maximum biomass recorded for forests in the area. This factor limits tree growth due to root competition.

FORCAT treats individual tree death as a stochastic process. The model assumes that only one percent of all seedlings of a species survive to reach the maximum age of that species. Trees which add less than 1 mm in diameter growth per

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[5] Roelle, James E., and John M. Bartholow. 1977. University of Colorado, Fort Collins, CO.

year have an increased mortality rate.

Two forms of regeneration are considered in the model: seedling establishment and sprouting. For each year of the simulation, the model determines which species are eligible to establish seedlings. Eligibility is based on the compatibility between the current plot conditions and the species' ecological requirements for successful seedling establishment. From the set of eligible species the model randomly chooses from one to three species. A random number of seedlings is added to the plot for each of the species selected.

Trees which have died during the previous year are checked to determine if they are eligible to sprout. Eligibility is based on the sprouting tendency of the species and a proper diameter of the dead tree. From the list of eligible trees, one tree is randomly selected and a random number of sprouts is added to the plot.

RESULTS AND DISCUSSION

The FORCAT model is still under development. The first version of FORCAT contained all the functions and factors discussed above except for the soil moisture growth reduction factor. This version of the model generated forest stands dominated by large tulip poplar (Liriodendron tulipifera).

The second version of FORCAT included the soil moisture growth reduction factor. The results of this version showed basal area dominance by the more xeric oaks. The model results were compared against a pre-harvest forest inventory collected by J. A. Muncy[6] and presented elsewhere in this conference.

The field data was collected on a stand (Table 1) between 50 and 75 years old. There is fairly good agreement between model and field data where the oaks are considered as a single group. However, the species composition within the oaks differs in the model and field data.

Table 1.--Basal area percent composition of Catoosa field data and FORCAT model results at 50 and 75 years.

	Basal Area Percent Composition		
SPECIES	FIELD DATA	MODEL-- 50 YRS	MODEL-- 75 YRS
Red maple (Acer rubrum)	1	12	11
Sugar maple (Acer saccharum)		7	6
Pignut hickory (Carya glabra)	3		
Mockernut hickory (Carya tomentosa)	1		
Dogwood (Cornus florida)	1	1	
White ash (Fraxinus americana)		1	
Sourwood (Oxydendrum arboreum)	4		
Virginia pine (Pinus virginiana)	6		
Black cherry (Prunus serotina)		2	1
White oak (Quercus alba)	4	3	
Scarlet oak (Quercus eoccinea)	27	7	5
Southern red oak (Quercus falcata)	14		
Blackjack oak (Quercus marilandica)	1		
Post oak (Quercus stellata)	28		
Black oak (Quercus velutina)	11	60	76
Sassafras (Sassafras albidum)		4	1

Modeling is an iterative learning process. Models are run and the results are compared against actual data and experience. If model results and data do not match, it is an indication that certain critical factors may be missing from the model. Such is the case with the current version of FORCAT.

The forests of the Cumberland Plateau have been subjected to a long history of man induced disturbances such as fire and logging. The next step is to include these disturbances as part of the model. It is, however, somewhat encouraging that the version of FORCAT described in this paper generates results which are not too dissimilar from the forests found on Catoosa. With the inclusion of fire, logging, and a more detailed browsing model we are hopeful that the model will generate even more realistic results.

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[6] Muncy, J. A., and E. Buckner. 1980. Stand development following clearcutting on the Cumberland Plateau in East Tennessee. Southern Silvicultural Research Conference.

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RELATIONSHIP OF FUSIFORM RUST INFECTION TO INTENSIVE CULTURE OF SLASH PINE[1/]

P. Y. Burns, S. C. Hu, and J. B. Awang[2/]

Abstract.--Growth was increased greatly by intensive culture in a southeastern Louisiana slash pine (Pinus elliottii Engelm.) plantation. At age 10, fusiform rust infection was 56 percent on stems in the intensive treatment compared to 18 percent in the control. The correlation between cankering and tree size was weak.

INTRODUCTION

Fusiform rust of southern pines, caused by the fungus Cronartium quercuum (Berk.) ex Shirai f. sp. fusiforme (formerly known as Cronartium fusiforme Hedgc. and Hunt ex Cumm.), is recognized as the most damaging disease of forest trees in the South. The incidence, distribution, and impact of fusiform rust have increased dramatically in much of the planted slash pine ecosystem since 1960 (Dinus and Schmidt 1977). The disease is particularly severe in young pine plantations because of the rust susceptibility of the two most widely planted species, slash (Pinus elliotii Engelm.) and loblolly pine (Pinus taeda L.).

A survey of economic damage due to fusiform rust in the South showed that stumpage losses amounted to $30 million annually, a loss of $750 million in finished wood products (Phelps 1974). Current losses in some areas of the South are serious, and there is a potential for greater future losses.

There is a trend in southern pine plantation management toward more intensive cultural practices in order to increase wood growth. The objective of this study was to evaluate the seriousness of fusiform rust on intensively cultured slash pine in southeastern Louisiana and to relate its incidence to diameter and height growth, mortality, and silvicultural practices.

METHODS

A study of intensive cultural management of slash pine was established in southeastern Louisiana. Four plots, each 0.30 ha in area, were established on a stream terrace site where a 40-year-old natural loblolly stand was making excellent growth. Oaks which are highly susceptible to fusiform rust are abundant in the forest surrounding the plots.

The soil of the study area is Kalmia very fine sandy loam, moderately well drained and moderately permeable. The climate is warm and humid during the summer and mild during the winter.

In the spring of 1970 one-year-old slash pine seedlings were planted on the plots at a spacing of 2.74 m x 3.66 m (997 trees per ha). The seed source was fast-growing high-quality trees in the same general area. A total of 299 trees were planted on each of the four plots. The site had been prepared several months earlier. The following cultural treatments were applied: Plot A--plowed before planting, irrigated, fertilized, brush control, and mowed; Plot B--same as Plot A except for irrigation; Plot C--fertilized and brush control; Plot D--control (no treatment).

Irrigation water was supplied to Plot A whenever available soil moisture dropped to 40 percent of field capacity. Fertilizers were applied to Plots A, B, and C one month after planting (7-40-6, 57 g per tree), at age 5 (ammonium nitrate and treble superphosphate, 224 kg per ha each chemical), and at age 8½ (8-8-8, 168 kg per ha). Plots A and B were mowed several times each year to control weed and grass competition. Brush on Plot C was controlled by cutting and by spraying with 2,4,5-T.

Trees were measured and stand characteristics calculated annually through 10 growing seasons on the interior 0.1716 ha of each plot.

[1/] Paper presented at Southern Silvicultural Research Conference, Atlanta, Georgia, November 6-7, 1980.

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Fusiform cankering on each standing tree was tallied during the ninth growing season (referred to for convenience as at age 8) and again at age 10. Each tree was classified into one of four classes: (1) no cankers; (2) one or more cankers on stem, none on limbs; (3) no canker on stem, one or more cankers on limbs; and (4) one or more cankers on stem and one or more cankers on limbs.

In statistical analysis, Chi square was used to test canker data, and correlation analyses were made to correlate cankering with tree dbh and height.

RESULTS

Stand characteristics, including percentages of stem- and limb-cankered trees, are shown in Table 1.

The more intensive the treatment, the greater was the average dbh, average height, and volume. Growth was apparently increased greatly by intensive culture. At age 10 the two plots (A and B) receiving the most intensive culture (plowing the site before planting, weed control, and fertilization) had four times as much cubic volume as the control.

The most intensively managed trees had the highest rate of stem cankering. At age 10, 56 percent of the trees on Plots A and B were stem-infected, while only 18 percent of the trees on control Plot D had stem galls. The percentage of trees on Plot C with stem cankers was twice the percentage found on Plot D. The geographic spread of stem infection was fairly uniform across each plot.

Limb cankers are potentially lethal if the canker is close enough to grow into the stem before the limb dies. Limb cankering in this study was more common on all plots than stem cankering. The relationship of intensive culture to limb cankering was weak or nonexistent.

The infection level at age 10 was significantly higher than at age 8, apparently due to new infections. By age 10, only 10 percent of the trees on Plots A and B had no cankers. Plot C had only 13 percent "clean" trees, and the control plot had 23 percent uninfected trees.

Mortality through age 10 was about 17 percent; it was nearly the same on each plot regardless of treatment. Recent mortality, between ages 8 and 10, was associated with stem cankering; every tree that died during this period had a stem canker at age 8. Mortality was apparently distributed at random throughout each plot.

The correlation between cankering and tree size was weak. Correlation coefficients for stem cankering and dbh on the four plots at age 10 varied from -0.11 to 0.16 and for stem cankering and height from -0.19 to 0.16. The average dbh and height of stem-cankered trees were approximately the same as that of trees without stem cankers. Stem infections were well distributed through the range of dbh classes.

DISCUSSION

The findings in this study are generally in agreement with those of earlier investigators. Intensive cultural management of slash pine by use of such practices as intensive site preparation, fertilization, and weed control increases fusiform rust infection (Gilmore and Livingston 1958, Dinus and Schmidtling 1971, Miller 1972, Malac and Brightwell 1973, May and others 1973, Hollis and others 1975, Powers and others 1975, Rowan 1977).

The progress of the disease during the past two years has been more rapid in all four plots than would have been predicted by using the age-eight percentages of trees with rust in the model developed by Schmidt and others (1979) for slash and loblolly pine plantations. Even on the control plot, rust incidence at age 10 is very high --78 percent. The study area is in a region of high rust-infection hazard for slash pine plantations (Squillace 1976).

Two adjacent loblolly pine plantation plots, established seven years before the slash pine plantation and treated similarly to Plots A and B, had only 8 percent stem infection at age 7 and 10 percent at age 17, much less than Plots A and B of the slash pine experiment at ages 8 and 10. Although exact comparison is not possible because of the different ages of the two plantations, on this site slash pine appears to be more susceptible than loblolly to rust infection, which is in general agreement with other research (Czabator 1971, Powers 1975).

The weak correlation between growth of individual trees and stem infection is generally in agreement with results of other investigations. Although Powers and others (1974) and Sluder (1977) found that stem growth of infected trees was reduced, others reported that rust does not affect growth significantly (Dell and Driver 1963, Dinus and Schmidtling 1971, Jones 1972). Perhaps, as thought by Holley and Veal (1977), the different results in the literature would be at least partially explained if investigators would rate severity of infection by measuring the percentage of the stem which is girdled.

Table 1.--Stand characteristics and fusiform rust infection in a slash pine plantation in southeastern Louisiana

Plot	Treatment	Trees per ha	Ave. dbh	Ave. ht.	Tot. vol.[1/]	Infected trees Stem	Infected trees Limb	Infected trees None
		No.	cm	m	m^3/ha	------ Percent ------		
			Age 8					
A	Intensive culture, incl. irrigation	839	13.4	9.01	37.9	35	66	26
B	Intensive culture, without irrigation	868	13.2	8.94	38.6	34	60	28
C	Brush control and fertilized	851	11.5	7.90	25.8	20	71	28
D	Control, no treatment	845	7.0	6.20	6.6	8	56	41
			Age 10					
A	Intensive culture, incl. irrigation	816	15.9	11.49	70.8	56	84	10
B	Intensive culture, without irrigation	833	15.8	11.55	70.6	56	87	10
C	Brush control and fertilized	839	14.1	10.21	52.8	36	87	13
D	Control, no treatment	828	9.4	7.96	16.2	18	78	22

[1/] Volume is total entire stem inside bark.

It is questionable whether losses to increased rust infection negate the increased growth from intensive culture. In our intensively cultured plots rust infection has not as yet (through age 10) caused extensive mortality. Although losses due to rust may exceed the benefits due to increased growth from intensive culture, data from Brunswick Pulp Land Company's slash pine plantations in Georgia showed that intensive site preparation was economically justified in spite of associated increases of rust infection up to 50 percent (Anderson 1977).

Forest managers need help in deciding whether to abandon an infected plantation, to thin out infected stems, or to leave the plantation undisturbed until the end of a normal of a shortened rotation. Wells and Dinus (1978) showed that stem infection five years after planting was a reliable predictor of rust-associated mortality in loblolly and slash pine plantations at age 10 years. Belcher and others (1977) presented guidelines for choosing between removing or thinning rust-infected slash pine stands in Florida, based on number of trees per acre and percentage of stems infected. Application of these guidelines to our slash pine plots shows that Plots A and B would be reproduced, Plot C would be cleaned by thinning at age 16 to 20 and grown to rotation age, and Plot D would be held until the end of the rotation.

Although direct control of fusiform rust in pine plantations is now impossible, useful recommendations for a regional control strategy have been made by Schmidt and others (1977). They include such practices as suppression of susceptible oaks; delayed fertilization; planting rust-resistant species such as longleaf, shortleaf, or sand pines on high-hazard sites; planting rust-resistant hybrids or seed sources; consideration of a shelterwood regeneration system; having an unevenaged distribution among stands; planting uninfected seedlings; sanitation thinnings; pruning of infected branches when basidiospores are not present; careful controlled burning to avoid igniting resinous stem cankers; and utilization of infected portions of trees for tall oil, turpentine, and certain kinds of pulp.

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