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SESBANIA

As An LDC Agro-forestry Resource

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Final Report

January 31, 1985

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Introduction.

Since early in 1982, the Department of Agronomy and Soil Science of the College of Tropical Agriculture and Human Resources at the University of Hawaii has conducted research on species of the genus *Sesbania* and their potential contribution to farming and agroforestry systems in the tropics and subtropics. This report reviews and summarizes the activities of the project. The findings of the project's experimental and information-gathering activities indicate that *Sesbania* species can play important roles in developing country agricultures and economies as sources of animal feed, pulp fiber, fuelwood, and biological nitrogen. Additional work with these plants should be untertaken in order to make further progress in the varietal selection and crop management activities initiated in the present program, and to advance selected plant materials into research phases emphasizing utilization.

A brief description of Sesbania.

Sesbania is a genus of about 50 species of fast-growing leguminous trees, perennial shrubs, and herbaceous annuals which grow year-round in the tropics and subtropics and as summer annuals in temperate zones. These plants often host exceptionally vigorous associations with nitrogen-fixing *Rhizobium* bacteria, characterized by rapid development of large, numerous root nodule clusters. Because the plants tolerate a range of soil environments considered difficult for most legumes, they can be sources of nitrogen fixation and biomass production on diverse lands which would not ordinarily permit legume growth. Species are found which flourish in soils which are low in phosphorus, or are saline, alkaline, acidic, waterlogged, or flooded. The use of sesbanias is confined to limited areas of the world where local knowledge has developed concerning their advantages, as in India where the annual Sesbania bispinosa has been extensively used as a green manure crop preceeding rice, and as in Indonesia where the perennial S. grandiflora is grown for fodder and soil improvement and has been a source of pulpwood. Both of these crops were recognized in National Academy of Science publications on promising tropical legumes and firewood crops. At a 1983 workshop on nitrogen fixing tree germplasm resources, Sesbania grandiflora was categorized at research priority level 1 for fodder and food and level 2 for fuelwood and soil amendment, and considered of potential importance to both the humid, and arid and semiarid tropics. Sesbania sesban also was inclused in NAS's "Firewood Crops, Volume 2" as a resource for arid and semi-arid regions. Each of these and a number of other sesbanias can become important multi-purposes sources of animal fodder, fuelwood, and pulp fiber and can contribute to people's diets by improving the fertility of the soils where they are grown.

A review of project activities.

The information-gathering function of the project has resulted in a comprehensive document summarizing available literature on the characteristics and uses of *Sesbania* species which will serve to introduce *Sesbania* to researchers in agriculture, plant science, and related specialty fields. A draft of this review is attached (Appendix 4), and the authors are seeking an appropriate means for its publication. Information has also been sought through correspondence which has solicited germplasm contributions, sounded the extent of interest and research focussed on sesbanias, and attempted to elicit experimental cooperation and continuing interaction. Certain individuals and institutions have thus been made aware of the project's activities, and some of them have contacted us for information and seeds. A list of *Sesbania* accessions and their sources, assembled by the Project Associate prior to and during the funded period, is given in Appendix 1. Individuals to whom *Sesbania* germ plasm has been distributed under the project are listed in Appendix 2. A list of persons contacted who are involved in *Sesbania* research, and their special areas of interest, is given in Appendix 3.

Experimental activities of the project have been of broad scope. Many of the species assembled in the germplasm collection had never before been tested agronomically. A species observation planting during the first project year allowed assessment of accession growth form and habit, genetic variability, flowering habit, and suitability for further experimentation. Seed was increased, permiting subsequent project experiments and dissemination to other researchers. Herbarium voucher specimens were taken for deposit in the University of Hawaii Herbarium (HAW), the Bishop Museum Herbarium (BISH), the Smithsonian Institution (U.S.), and in the Kew Herbarium for identification by cooperators there.

In order to have an effective Rhizobium inoculum for experimental use, and to ascertain the extent of host-strain compatibility within the genus, strain tests were performed using various Sesbania species inoculated with a number of Rhizobium isolates obtained from sesbania nodules. The result was the selection of a strain mixture capable of nodulating most sesbanias and showing high nitrogen-fixing (acetelene reduction) activities. A similar test was done subsequently by this department's NifTAL Project (P.O. Box "O", Paia, Hawaii 96779), from which researchers may obtain inoculants for Sesbania species.

Experiments on the tolerances of sesbanias to various soil conditions were conducted in pots in the glasshouse. Their ability to tolerate waterlogging and flooding was confirmed and found to be present in the majority of sesbanias tested. Most of them develop aerenchyma tissue along stems and roots in response to flooding; large intercellular spaces in this tissue allow air to travel beneath the water level and permit root respiration and nodule activity under conditions which would stop N-fixation in most legumes. At least one species has the unusual capability to produce stem nodules, increasing the potential for development of nodule mass with the possibility of substantially increasing N accumulation. These unique tolerances and abilities afford opportunities for sesbanias to provide nitrogen to rice cropping systems.

Because rice-growing soils are often deficient in phosphorus (P), a sesbania promising as a green manure was grown in a P-deficient paddy soil to which increasing levels of fertilizer P had been applied some years previously. Good growth and lack of a marked response to increasing soil P levels offered the possibility that under flooded conditions the low phosphorus fertility characteristic of many rice-growing soils will not severely limit sesbania growth.

Tolerance of soil acidity by selected sesbanias was studied using an Ultisol typical of the infertile, acid, leached, aluminous soils common in the tropics, and an Oxisol containing toxic levels of manganese. A suite of 28 sesbania accessions was tested in these soils, with or without lime. There was a relatively consistent tolerance to soil aluminum but a variable tolerance to soil manganese among these accessions. Plant accessions which demonstrated varying degrees of aluminum tolerance were grown in a third experiment, testing response to applied phosphorus with and without lime and mycorrhizal inoculant. These studies have added to our knowledge of the range of acid soil adaptation in sesbanias, thus far confined to unsubstantiated reports that certain species tolerate acid upland tea-growing soils of Assam, or the severely reduced acid sulfate soils found in South-east Asia. Results of this series of experiments are being prepared for journal submission. The tolerances indicated by these studies indicate that field studies on acid soils would be appropriate.

Tolerance of soil alkalinity and soil salinity among sesbanias is well known, because of the use of S. bispinosa for saline-alkali soil reclamation in India. Our project has supplied Sesbania seed to two scientists for studies on salinity tolerance (see Appendix 2).

Growth experiments at field sites were an important part of the project's assessment of sesbanias. The observation planting provided information on differences among accessions and allowed a preliminary selection of better varieties. Observations on flowering, seed yields, and pest incidence were also made. Certain accessions were then moved on to yield trials, with annual and perennial species grown in seperate experiments. Drafts of reports on these experiments prepared for submission as journal articles are attached (Appendix 5, 6).

One yield trial compared biomass production of 35 annual accessions over a 3-month period during the summer. Plots were sown at a population of 125,000 plants/ha (20 x 40 cm), which encouraged vertical growth and stem production. Such a planting should be typical of a pulpwood plantation, and results indicate that annual sesbanias are promising materials for pulp and paper industries in developing countries. Dry matter production levels of the more productive entries were in the range of 13-17 tons/ha on the medium fertility site to which only phosphorus fertilizer had been applied. Nitrogen contents of harvested tops of these entries ranged from 150 to 225 kg/ha. Further studies should seek optimal planting densities and fertilizer inputs for maximized biomass yields, and should examine the dynamics between plant population and growth period, carbon-nitrogen accumulation ratios, and the ratio of above-ground and below-ground yield components as it affects soil organic carbon and soil nitrogen benefits to subsequent crops.

Simultaneous to this planting, a subset of 10 of the 35 annual entries was sown separately to determine production over a shorter period, as for a green manure crop, and regrowth in response to cutting. The nitrogen content of tops harvested seven weeks from planting was about 100 kg/ha, and the regrowth of 6 out of 10 entries yielded an additional 100 kg/ha nitrogen at a second cut five weeks later.

A second yield trial compared perennial sesbania accessions for fodder production. Varieties of S. sesban, one endemic Hawaiian sesbania, S. formosa, and several S. grandiflora accessions were included, plus two non-sesbanias, Leucaena leucocephala and Calliandra callothyrsus; in all, 17 sesbania accessions were tried. The data indicated very rapid initial growth and regrowth after cutting for some sesban entries, and high production levels greater than those of leucaena for most sesbanias. Future work with perennial sesbanias should determine optimal harvesting manner and interval, seasonal variation on growth, management techniques to regulate fuelwood-forage yield ratios, response to fertilizer applications, and feed quality. Such additional information would be relevant to an array of users, from leaf protein extraction industries to subsistance farmers raising ruminant animals.

Project-Related Publications

Evans, D.O. Sesbania flowering observations. Nitrogen Fixing Tree Research Reports 1:42. 1983.

Evans, D.O. Search for seed of Sesbania grandiflora. Nitrogen Fixing Tree Research Reports 1:43. 1983.

Evans, D.O.; Yost, R.S.; and Lundeen, G.W. A selected and annotated bibliography of tropical green manures and legume covers. Hawaii Institute of Tropical Agriculture and Human Resources Research Extension Series 028. 1983.

Evans, D.O. Preliminary observations evaluating perennial sesbanias for fodder production. Nitrogen Fixing Tree Research Reports 2:32. 1984.

Evans, D.O.; and Rotar, P.P. Productivity of Sesbania species: 1. Annual species with and without cutting management. submitted: Tropical Agriculture (Trinidad).

Evans, D.O.; and Rotar, P.P. Productivity of Sesbania species: 2. Perennial species for fodder production. submitted: Tropical Agriculture (Trinidad).

Evans, D.O.; and Rotar, P.P. Sesbania species for agriculture. in review.

Huang, R.S.; and Evans, D.O. Response of Sesbania species to lime and phosphorus in aluminum and manganese dominated acid soils. (tentative title) in preparation.

The Project Associated is listed as a Research Contact in Firewood crops: Shrub and tree species for energy production, Volume 2. (National Academy of Sciences, 1984) regarding Sesbania sesban.

The Project Associated is listed as a Sesbania seed source in Suppliers of Germplasm of Nitrogen Fixing Trees (J.W. Turnbull, CSIRO Division of Forest Research Report No. 16, 1984).

SESBANIA SPECIES ACCESSIONS
DEPARTMENT OF AGRONOMY AND SOIL SCIENCE
UNIVERSITY OF HAWAII

ACCESSION CODE	NAME AS RECEIVED	GEOGRAPHICAL ORIGIN	DONOR DESIGNATION
SESBAN ACCESSIONS			
SB1	sesban	Kenya	
SB2	sesban	Belgian Congo	PI 247857
SB4	sesban	China	PI 279601
SB5	sesban	Sri Lanka	
SB6	sesban	India	PI 228236
SB7	aegiptiana	Venezuela	CIAT 0767
SB8	sesban	India	PI 215608
PD1	paludosa	Hainan PRC	
PD2	paludosa	S. Vietnam	
X2	sp.	Brazil	CIAT 7934
SB9	sesban	Rwanda	
SB10	sesban	Venezuela	CPI 28114
SB11	sesban	Burma	CPI 30774
SB12	sesban	Ugnada	CPI 32223
XW	sp.	Pakistan	
B49	aculeata	Pakistan	
SB13	sesban	Egypt	NFT 159
SB14	sesban	Java	
SB15	sp.	Egypt	
SB16	sesban var. nubica	Zimbabwe	HDLC 346
SB17	sesban	Uganda	
SB18	sesban	Mauritius	
SJ2	javanica		CPI 34853

ACCESSION CODE	NAME AS RECEIVED	GEOGRAPHICAL ORIGIN	DONOR DESIGNATION
BISPINOSA/CANNABINA SPECIES COMPLEX			
BA1		India	USDA BN 14717 62
BA2		India	KAR, PI 430522
BA3		India	CRRI
SC1	sericea	Australia	PI 284844
CB1	cannabina	India	PI 180050
CB2	cannabina	Hainan PRC	
BA4	bispinosa	PR China	
EX1	exasperata	Brazil	PI 322626
EX2	exasperata	Argentina	PI 337595
BA5	aculeata	India	
CB3	cannabina	N. Vietnam	
CB4	cannabina	S. Vietnam	
CB5	cannabina	Australia	Waimea 74S46
BA6	sp.	India	CSSI
EX3	exasperata	Surinam	CPI 63925
SC2	sericea	Surinam	CPI 63926
CB6	cannabina	Australia	CQ 1424
CB7	cannabina	Australia	CQ 1445
CB8	cannabina	Botswana	CPI 78174
BA7	bispinosa	India	CPI 71021
BA8	bispinosa	India	CPI 71022
·SM1	simpliciuscula	Australia	CQ 1425
BA10	sp.	S. India	
BA11	sp.	Bhola I, Bangladesh	
BA12	bispinosa	India?	

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ACCESSION CODE	NAME AS RECEIVED	GEOGRAPHICAL ORIGIN	DONOR DESIGNATION

SUBGENUS AGATI ACCESSIONS

GL1	grandiflora (c)*	Hawaii	
GL2	grandiflora (w)*	Hawaii	
GL3	grandiflora (w)	Philippines	
GL5	grandiflora (w)	Guatemala	CATIE 1147, NFT 383
F01	formosa	Australia	CQ 1614
F02	formosa	Australia	CQ 1146-26, NFT 167
GL6	grandiflora (c)	Java	
GL7	grandiflora (w)	Java	
GL8	grandiflora (w)	W. Samoa	N-207
GL9	grandiflora (w)	Hawaii	NFT 303
GL10	grandiflora		NFT 374
GL11	grandiflora	India	NFT 519
GL12	grandiflora	Hawaii	NFT 557
GL13	grandiflora	Java	N-67
GL14	grandiflora	Thailand	N-78
GL16	grandiflora	Indonesia	PI 477302
GL17	grandiflora	India	N-280
GL18	grandiflora	India	

* c = red-flowered, S. grandiflora var. cocinnea.
w = white-flowered.

OTHER DISTINCT SPECIES ACCESSIONS

PC1	pachycarpa	Belgian Congo	PI 247856
PC2	pachycarpa	Senegal	
PC3	pachycarpa	Senegal	CPI 50978
PC4	pachycarpa	Togo	
SP1	speciosa	Sri Lanka	PI 219851
SP2	speciosa	Sri Lanka	
TP1	tetraptera	Swaziland	PI 365143
AB1	arabica	Turkey	PI 167290
AB2	arabica	Afghanistan	PI 212624
AB3	arabica	Afghanistan	PI 167069
SJ1	javanica	Australia	
MN1	macrantha	Rwanda	
MN2	macrantha	Zimbabwe	HDLC 2198
MN3	macrantha	Tanzania	
MN4	macrantha	Tanzania	
MP1	microphylla	Zambia	CPI 39939
MP2	microphylla	Zimbabwe	HDLC 2199
CH1	cochinchinensis	Hong Kong	CPI 91846
CO1	coerulescens	Zambia	CPI 39938
CO2	coerulescens	Zimbabwe	HDLC 2197
RS1	rostrata	Senegal	
RS2	rostrata	Zimbabwa	HDLC 346
EB1	erubescens	Australia	CQ 1776
BR1	brevipeduncula	Zimbabwe	HDLC 445

C

ACCESSION CODE	NAME AS RECEIVED	GEOGRAPHICAL ORIGIN	DONOR DESIGNATION

UNIDENTIFIED SPECIES ACCESSIONS

XJ		Sri Lanka	
XA		U.S.	PI 302088
X1		Venezuela	CIAT 0708
XE7		Taiwan	E7
XE8		Taiwan	E8
XE70		Taiwan	E70
XE3		Taiwan	wild
X31		Brazil	CIAT
X32		Brazil	CIAT
X33		Brazil	CIAT
X35		Brazil	CIAT
X62		Cuba	CIAT
SB3	sesban	Okinawa	USDA 233551

HAWAIIAN SPECIES ACCESSIONS

SO1	oricola	Oahu, Hawaii	
TO1	tomentosa		
TO2 (AR5)	arborea	Molokai, Hawaii	PMC
AR1	arborea	Molokai, Hawaii	Waimea 74S921
AR2	arborea	Molokai, Hawaii	
AR3	arborea	Molokai, Hawaii	
AR4	arborea	Molokai, Hawaii	
MK1	manaensis	Kauai, Hawaii	

NEW WORLD SPECIES ACCESSIONS

VC1	vesicaria	Texas	
VC2	vesicaria		PR-43963
DM1	drummondii		PR-43878
DP1	punicea	U.S.	
DP2	punicea	R.S. Africa	
DP3	punicea	Brazil, Sao Paulo	
DP4	punicea	U.S.	NU-53123
MG1	marginata	Uruguay	PI 175007
XG	sp.	Brazil	
VG1	virgata	Brazil	
XP	emerus	Peru	
MA1	macrocarpa	Australia	PI 168623
MA2	macrocarpa	Mexico	PI 296055
MA3	macrocarpa	Uruguay	PI 175006
MA4	sp.	Arizona	64-635-B01

APPENDIX 2.

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LIST OF RECIPIENTS OF SESBANIA SPECIES GERMPLASM

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1151 Punchbowl St., Honolulu, Hawaii
S. arborea AR4, T02; S. formosa F02.
Adaptability trials, Molokai, Hawaii

M.D. Benge
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S. sesban SB10, XW, SJ2, S. bispinosa BA12
Distribution

P.K.R. Nair
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S. sesban SB1, SB10, XW, SB9
Observation trial, Kenya

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S. bispinosa BA6
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Rhizobium strain compatability

E. Hansen
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Davis, CA
GL17, BA6, SB1, RS1, SB13, EX3, PC2
Salinity tolerance studies

S.N. Desai
All India Coordinated Project for Research on Forage Crops
SB1, SB13, SB9, SB2.04
Observation

C.-K. Pan (Pan Chih-Kang)
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SB13, GL17
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GL17
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SB13
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SB1, MN1, SJ1, GL17, CO1
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Observation, Laos

R. Muniappan
SB1, SB10
Observation, Guam

C. Cross
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SJ2, SB9, SB13
Seedling ecology study

R. Weejwardena/N. Glover
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Candidate green manure, flooded conditions

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seed gums

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See also: Appendix 2.

SESBANIA SPECIES FOR AGRICULTURE

A State-of-the-Knowledge Review

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January 31, 1985

DRAFT
Pending Review
Subject to Revision

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Acknowledgment.

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All reported opinions, conclusions, and recommendations are those of the authors and not those of the granting agency or the U.S. government.

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B. Ben Bohlool, Mitiku Habte, Reuy-Shang Huang, Sombath Somphone, and Russell S. Yost helped with various aspects of the investigations on Sesbania, and their collaboration is much appreciated.

INTRODUCTION.

Agriculture is a process of bringing plant growth under control and modifying it so as to produce -- it is hoped -- the maximum benefit to man. Food production has always been the paramount goal. As agricultural systems have developed, plants for purposes other than food have come under management, to produce feed for animals, fiber for clothing, cordage, and paper, wood for fuel and structures, and other industrial and medicinal products.

Many of these secondary agricultural commodities were once gathered from naturally occurring plant communities. Much of the firewood consumed by man is still collected from forests or from sub-arable, uncropped lands. By encroaching on these lands and bringing them under cultivation, we destroy these natural resource systems, thus bringing upon ourselves the burden of growing what was once provided by nature. For example, we must grow the fuelwood to cook the grain (which has usurped most lands for miles around) and to heat the homes of people whom the grain is grown to feed. We also bear the responsibility, too often unacknowledged, to manage our lands in ways which preserve them and sustain their productivity.

Unfortunately, our needs to use lands have grown faster than our understanding of ecological processes, faster than our traditional attitudes toward land use can change, faster than our imaginations can evolve to deal creatively with the dangers and challenges implicit in our actions.

This report describes the characteristics and the past and potential uses of plants in the genus Sesbania. Most of these plants are still wild, a few have been 'discovered' recently, and some have long been in use by farmers in certain parts of the world.

Sesbania species are not food plants, except in some minor instances where leaves and flowers are consumed as vegetables. They serve subsidiary purposes when brought into cultivation. The major use for which they are known is as green manures to improve production of food crops. To lesser extents they are grown for animal fodder and for their wood for fuel, poles, and light construction. They have been adopted for these uses because agriculturists have been impressed by their special qualities of vigorous growth, adaptation to varied soil environments, and enhancement of soil fertility where they are grown.

Some potential uses of Sesbania have obvious benefits. There is great scope for expanded use of perennial Sesbania species to improve animal nutrition. Selection of appropriate varieties of annual species for pulpwood and development of agronomic techniques to grow them for pulp fiber can provide a new cash crop and foster local industries in developing countries where increased literacy and consumerism increases demands for paper. The expanded use of Sesbania species' biologically produced nitrogen in cropping systems even has egalitarian qualities: instead of submitting to the grip of the moneylender to buy fertilizer to increase yields, farmers can themselves provide home-grown, low-cost inputs to their production systems. Using appropriate agronomic techniques and farm management skills, and seed grown on the farm, farmers can be aided by these legumes in pulling themselves up by biological 'bootstraps'.

There are other less obvious benefits to be gained by expanding roles of legumes such as Sesbania species for agriculture. These involve the concepts of diversified cropping and conservation-effective cropping. Both of these concepts are increasingly important as their role in long-term maintenance of soil productivity is recognized. Crop diversification implies a variegated agricultural resource base and localized self-sufficiency for numerous agricultural products. Variety in plant types and functions promotes nutrition and soil fertility, insures against crop failure, provides genetic reservoirs, is universally pleasing; it imitates nature. Conservation-effective cropping implies an integration of plant materials and management techniques such that the soil surface is protected from erosive forces, soil structure is maintained in the most favorable condition, soil nutrients are cycled, and soil loss is minimized. It too imitates nature. These concepts are derived and intimately related by their foundations in nature, and their conceptualization is necessitated by our lack of harmony with it, our lack of sufficient respect for it, our lack of proper husbandry of it.

Sesbania species are plant resources which are valued highly by those who know and use them. This report is presented to broaden the acquaintance of scientists and agriculturists with these plants, so that they might be more appreciated, studied, and utilized. We have not intentionally neglected or misrepresented any aspect of *Sesbania* research and utilization, but if we have done so, correction by our readers will be received with appreciation.

1. BOTANY OF SESBANIA.

The genus Sesbania Scopoli is placed in the family Leguminosae, subfamily Papilionoideae; it has recently been moved from the tribe Galegeae to the tribe Robinieae by Polhill & Souza (1981). With about 50 species distributed in the tropics and subtropics, Sesbania is one of the smaller genera in the Papilionoideae but is the largest of the 21 genera in its tribe.

Sesbania species are divided into at least 4 subgenera, of which two, Sesbania and Agati, contain species of potential agricultural value. The subgenus Sesbania comprises most of the species, is distributed worldwide, and contains species known as green manures and as forages, such as S. bispinosa and S. sesban; the subgenus Agati of southern Asia contains the tree species S. grandiflora and S. formosa. The other subgenera contain New World species and, like Agati, have occasionally been given generic status; indeed, there is continuing disagreement over the placement of the subgenera Daubentonia and Glottidium in Sesbania; the present concensus appears to be that the monospecific, North American Glottidium is excluded (Gillett, 1963; Polhill & Souza, 1981).

There are taxonomic studies of Sesbania for Africa (Gillett, 1963), Australia (Burbidge, 1965), and Hawaii (Char, 1983). A recent dissertation on New World species (Montiero) has not yet been published. There is a real need for a synoptic study of the Asian species of Sesbania.

Gillett (1963) recognized 33 species occurring in Africa, a diversity unknown elsewhere. Burbidge (1965) found 10 species in Australia, of which perhaps 8 are endemic to that continent. All of the 7 Hawaiian species described by Char are endemic to those islands, their nearest relation being, perhaps, S. atollensis, a South Pacific species.

While the number of Asian species is not known, it appears that the wide distribution of some of them, including S. bispinosa and S. sesban, is because of their occurrence in cultivation. The only species of fairly certain Asian origin is the pantropically distributed S. grandiflora. This species is principally spread by man; most flora describe it as introduced and in cultivation, and we have not found any flora claiming it as native, or any reference to naturally occurring populations, nor have we observed any volunteer seedlings in the vacinities of trees growing in Hawaii. Most other sesbanias seem capable of propagating themselves.

Sesbania species are relatively short-lived, the majority being annuals. Taxonomic studies are generally vague in describing growth duration. Known perennials include S. grandiflora, S. formosa, S. sesban, and the Hawaiian species. S. grandiflora may live 20 years or so (Char, 1983), while members of the S. sesban complex may be shorter-lived. The New world shrubs S. punicea and S. tripetii are also perennial. Some degree of perenniality has been observed in Hawaii in S. javanica from Australia and S. pachycarpa from Africa, and forms of S. macrantha growing in different regions of Africa exhibit varying growth durations (K. Egger, personal communication). Some herbaceous species which come from subtropical zones bordering on temperate latitudes appear to be particularly short-lived when grown in Hawaii (latitude 21 degrees N), having a determinate growth habit characterized by early flowering and senescence after a reproductive phase. Examples are S. exaltata from the southern U.S.A., and S. arabica from Turkey and Afghanistan. Most other tropical annuals in the genus (e.g. S. cannabina from Australia and S. Asia, S. emerus from S. America) are less precocious and have a life span of at least 6 months.

The reader is referred to one of the taxonomic treatments already cited for a detailed discussion of Sesbania species morphology. Germination in Sesbania is epicotyl, the first leaf is juvenile and entire and subsequent true leaves are pinnate and demonstrate diurnal solar tracking and leaf and leaflet folding at night. Flowers are usually borne in loose racemes. Seed pods are usually cylindrical but some are rectangular in section (e.g. S. grandiflora, S. speciosa, S. marginata) and S. tetraptera has 4-winged pods. The pods are generally indehiscent and do not shed their seed until well after pod maturity.

Char (1983) describes flower coloration: "The majority of the Sesbania species have yellow colored flowers, pale yellow to orange-yellow, which may sometimes have dark purple or purplish-brown streaks or mottling on the backs of the standard petals. The flowers range in size from 0.5 to 2.8 cm long. Two species, S. erubescens and S. coerulescens have flowers which are pale blue to deep blue. Sesbania formosa and S. grandiflora, on the other hand, have large, white or creamy colored flowers, 7.5 to 9 cm long. There is also a dark reddish-purple flowered variety of S. grandiflora (var. coccinea). The Hawaiian taxa as well as S. atollensis...are intermediate in size between the smaller-flowered species and the larger-flowered species. The flowers range in size from about 2.5 to 4.6 cm long. The Hawaiian species have orange-red to crimson or dark red flowers, while S. atollensis has scarlet to maroon or deep red (with spots) flowers."

Sesbania flowers are most widely pollinated by members of the Hymenoptera. In Hawaii, the carpenter bee (Xylocopa sonorina) and the honey bee (Apis mellifera) are common pollinators. In India, a mason bee, the solitary Megachile lanata, has been noted (Chaudhary & Jain, 1978); In Hawaii, Char (1983) suggests that the native solitary bees Nesoprosopis spp. were probably the original pollinators of Sesbania. Honey bees have been noted to forage heavily on sesbanias in parts of India (Chaturvedi, 1977) where Sesbania spp. pollen is a prodominate source during July, and in Egypt, where Sesbania and alfalfa (Medicago) are major sources in spring and summer (Ibrahim, 1976).

Duration of seed viability varies with species and with seed storage conditions. S. exaltata seed was 29% viable after 2.5 years when buried in soil in a study of weed seed survival (Egley & Chandler, 1978). S. grandiflora seed has lost viability in 2 years of storage at ambient conditions in Hawaii; S. bispinosa seed also probably loses viability within a few years, although for either species storage at low relative humidity and temperature may prolong viability. Other species' seed may be longer-lived: 15-year-old seed of S. speciosa obtained from USDA was found viable.

Most species' seeds have impermeable seed coats and require scarification. This seed coat dormancy allows survival over time, transmittal along waterways (Trivedi, 1955), and helps to assure that germination occurs when an abundance of water is available for growth. Seeds harvested from the same plant at different periods of pod set have been observed to have variable hardseededness (Sharma et al., 1978). Seed coat structure and related imbibition characteristics in S. bispinosa and S. punciea have been investigated (Graff & van Staden, 1983) and increased permeability was associated with differences in the macrosclerid layer cell packing of "rust" colored seeds of both species. Variation in seed color between light green or tan and reddish-brown or brown is common in individual plants of some Sesbania species.

Seed scarification is recommended when sowing sesbanias in order to obtain uniform, complete, and rapid germination. For research purposes, soaking in concentrated sulfuric acid followed by thorough rinsing in water is common; hot water treatment may also be effective. S. grandiflora germinates well without scarification, although mild treatment (e.g. 15 minutes in acid) assures rapid, more even germination. Most Sesbania species germinate well when acid-scarified for 30 minutes, although several (including (*S. speciosa*, *S. tetraptera*, and *S. rostrata*) require 45-60 minutes or more before all seeds will imbibe.

Vegetative propagation is possible with stem and branch cuttings of perennial sesbanias such as *S. grandiflora* and *S. javanica*, and *S. sesban* seems especially easy to propagate in this manner. Experiments with in vitro tissue culture of *S. sesban* and *S. grandiflora* have been reported by Khattar and Ram (1982, 1983).

Plant breeding research on *Sesbania* has been very limited. Datta and Sen (1960) and Datta and Bagchi (1971) attempted some crosses between species, but without success.

The *Sesbania* germplasm resource base has likewise received inadequate attention to date. The collection of approximately 125 accessions maintained at the Department of Agronomy and Soil Science, University of Hawaii, is perhaps the largest in existence. A wider collection of materials, particularly from Africa and South Asia, is imperative for future selection and breeding activities.

There have been a number of botanical studies on morphology in various *Sesbania* species. In studies of floral anatomy, Datta and Maiti (1968) compared the vascular systems of *Sesbania* flowers with those of other legume genera. Tewari and Nair (1979) studied tissue bands on floral wing petals. Leaf cuticle structure in a number of legume genera including *Sesbania* was compared using electron microscopy (Kravkina, 1976). Ghouse and Yunus (1976) analyzed vascular cambium in *S. sesban* and numerous other leguminous trees. A specific study of S. punicea wood (Cozzo, 1976) focussed on variability in stratification and other features among a population of plants. Stem bark characteristics of S. sesban and S. grandiflora were studied and related to medicinal properties of their bark powders (Chaudhuri, 1966).

Pollen of S. roxburgii was described and illustrated by Huang (1972). Pollen physological development has been observed for S. grandiflora (Chitaley & Naik, 1971), for S. aculeata (S. bispinosa) (Singh, 1957), for S. sesban (Ganguly and Datta, 1961), and for S. benthamania (Datta and Choudhury, 1967). Pistil and stamen morphology in S. grandiflora was studied by Chakraverti (1953). Embryology in S. aculeata (S. bispinosa), S. procumbens, and S. grandiflora was described by Seshavatharam (1982) and in S. sesban and S. grandiflora by Rau (1951). Mitosis has been studied in S. sesban by Ganguly et al. (1962) and in S. paludosa by Datta and Choudhury (1968). Dana and Datta (1960) studied pollen morphology and growth, mitosis, karyotype, and meiosis in S. bispinosa and S. speciosa. Studies of the megametophyte of S. bispinosa were reported in a series of articles by Salgare (1974). Trivedi et al. (1978) studied the spermoderm with electron microscopy. Reports of chromosome numbers in Sesbania are summarized in Table 1. In addition to the species entered there, S. formosa, S. coccinea, and S. sp. from Timor have been found to have 2n=24 (R.L. Oliver, personal communication).

Table 1. Chromosome numbers of some *Sesbania* species (after Char, 1983).

Species	gam.	spor.	Authority
S. arborea (Rock) Deg. & Deg. (S. tomentosa f. arborea Rock)	12		Carr (1978)
S. benthamiana Dom.	12		Datta & Bagchi (1973)
S. bispinosa (Jacq.) Wight. (S. aculeata Pers.)	6,7,12	12,24	Jacob (1941), Haque (1946), Sampath (1947), Bir & Sidhu (1966, 1974), Baquar & Akhtar (1968), Dana & Datta (1960)
S. cannabina (Retz.) Poir.	6		Al-Mayah & Al-Shehbaz (1977)
S. coerulescens Harms	6,7		Datta et al. (
S. cinerascens Welw. ex Baker		12	Gillett (1963), Lubis et al. (1981)
S. concolor Gillett	12		Baquar & Akhtar (1968)
S. drummondii (Rydb.) Cory	6		Turner (1955)
S. exaltata (Raf.) Cory (S. macrocarpa Muhlenb. ex Raf.)	6		Atchison (1949), Turner (1955)
S. grandiflora (L.) Poir.	12	24	Jacob (1941), Haque (1946), Rao (1946), Sampath (1947), Tjio (1948), Lubis et al. (1981)
S. javanica Miquel		12	Lubis et al. (1981)
S. keniensis Gillett		12	Gillett (1963)
S. letocarpa DC.		12	Miege (1960)
S. marginata Benth.	6		Di Fulvio (1973)
S. microphylla Harms		6,12	Gillett (1963), Datta et al. (1973)
S. procumbens (Roxb.) Wight. & Arn.		12	Bhaskar & Devi (1976)
S. punicea (Cav.) Benth.		12	Covas & Schnack (1946)

S. quadrata Gillette		12	Gillett (1963)
. sericea (Willd.) Link		24	Frahm-Leliveld (1953)
S. sesban (L.) Merr. (S. aegyptiaca Poir.)	6,7,8	12	Jacob (1941), Haque (1946), Sampath (1947), Baquar et al. (1965), Lubis et al. (1981), Bir et al. (1975) Sareen & Trehan (1979)
S. sesban var. bicolor (Wight. & Arn.) Andr.	6,7	12	Baquar & Akhtar (1968), Bir et al. (1975), Sareen & Trehan (1979)
S. sesban var. nubica Chiov.		12	Gillett (1963)
S. sesban var. picta Santapau	6,7,8, 14	12,14, 16,28	Bir & Sidhu (1966) Bir et al. (1975)
. sesban subsp. punctata (DC.) Gillett (S. punctata DC.)		12	Frahm-Leliveld (1953)
S. speciosa Taub.		12	Jacob (1941), Sampath (1947) Simmonds (1954), Datta & Sen (1960)
S. tetraptera Hochst. ex		12	Senn (1938)
. tomentosa H. & A.	12		Carr (1978)
S. vesicaria (Jacq.) Ell. (Glottidium vesicarium (Ell.) Rydb.)	6		Turner (1955)

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2. AGRICULTURAL USES OF PERENNIAL SESBANIAS.

Only two perennial sesbanias have been used to any extent for agricultural purposes: *S. sesban* and *S. grandiflora*. Perennial sesbanias endemic to the Hawaiian Islands are mostly halophytic shrubs inhabiting coastal zones; they and the taller-growing *S. arborea* found at 100-300 m elevation on Molokai are quite drought tolerant and are browsed by cattle, feral goats, and deer. The Australian endemic *S. formosa* also appears to be drought tolerant from its performance in observation plantings on Oahu (Evans, unpublished) and Molokai (R. Skollmen, personal communication). Hardly any of the woody shrubs and small trees cataloged in the African center of *Sesbania* species diversity (Gillett, 1963), other than the sesbans, have known agricultural uses or have been evaluated agronomically.

S. grandiflora has been recognized (NAS, 1979, 1980) for its rapid growth and multiple uses, principally for fuelwood and pulpwood but also for fodder. This tree has pantropic distribution, principally by man, but reports of its use as a fodder source are confined to South and South East Asia. It is considered native to the Old World tropics, but most floras of these areas describe it as introduced. Gillett (1963) speculated that it had been introduced to Africa from Indonesia. We have not found any floristic literature claiming it as native, or any reference to wild populations.

Sesbania sesban has been recognized as having potential as a fodder crop, but this potential is generally known only locally.

Where it occurs as an element of riverine vegetation in Africa, it is browsed by cattle, and Gillett (1963) reports that it is called "mu" in one region because of the eager cries of cattle led into the stands. In northern Rwanda, such stands were selectively and intensively utilized by elephants translocated to a national park, resulting in heavy damage to the plants (Monfort and Monfort, 1979). In addition to its native habitats of tropical Africa, Townsend (1973) states that sesban is cultivated and semi-naturalized in Cyprus, Egypt, Tunisia, Arabia, Bahrain, Iran, Pakistan, Afghanistan, India, Sri Lanka, Burma, Thailand, Java, Australia, and South America. It is grown as an annual in Iraq and other of these areas where its life is abbreviated by frost, but otherwise it is perennial. It is often grown as a temporary hedge and windbreak, and lopped for fodder.

Miscellaneous uses of Sesbania species.

Information on agroforestry uses of sesbanias in combination with other crops is very limited, and has been quantified to a much lesser extent than have been their uses as green manures.

Bally and Legros (1936) listed reported uses for sesbanias in combination with other crops as support or as shade. *S. sesban* has been used to shade crops such as coffee, cacao, and tumeric; *S. macrantha* also has been used to shade coffee in Uganda. *S. sesban* and *S. grandiflora* have been grown as live standards for pepper (*Piper nigrum*) and betel vine (*Piper betel*). *S. grandiflora* has been used to shade coconut nurseries in India (CSIR, 1972). As grown for betel vine in S. India, grandiflora is usually given 1-3 months start before sowing the betel, is kept free from side branches to about 3.6 m, and is topped periodically to minimize shading (Aiyer, 1980).

Nao (1979) has reported the interplanting of S. grandiflora with fruit trees in "home gardens" in the Mekong delta of southern Viet Nam. These gardens are considered to be modified forest ecosystems, and recognition of the legume's contribution to soil fertility seems to be the reason for grandiflora's inclusion. It is not used for fuel (coconut leaflets being preferred) but the flowers are cooked and eaten as vegetables, and the leaves are used as mulch or as protein-rich fodder to supplement rice straw in animal diets.

S. sesban has been used as a windbreak for banana in India (Anon, 1958; Baweja, 1955) and in Africa (Karani, 1983). It has been used as a multi-purpose planting in the demonstration agroforestry Project Agro-Pastoral in Myabisindu, Rwanda (T.H. Zeuner, personal communication, 1982). S. grandiflora has been used as a windbreak for citrus and coffee in the West Indies, and for banana in India, where it is said to be particularly effective when topped, which would encourage branching (CSIR, 1972).

Border planting of sesbanias around cropped fields for green leaf manure and other purposes was discussed in the section on green manuring. In similar border-planted situations with rice, the flooding tolerance of some sesbania species has been exploited. As a border crop for deepwater rice, sesbanias have been used in Bangladesh to prevent invasion by weeds such as water hyacinth (Catling et al., 1983) and in India to protect the rice crop from wave action (Kaul and Roa, 1960). In large paddy fields, borders of sesbania also serve to protect bunds from erosive deterioration by waves generated by winds. Generally, species so used are the annuals S. cannabina and S. bispinosa.

Agro-pastoral uses of perennial sesbanias.

There have been some experiments using sesbanias as components of two-tier grazing or fodder production systems. S. grandiflora was sown aerially in mixture with other legume trees to regenerate a formerly forested site in central Java, Indonesia, which had been prepared by either burning or mechanically disturbing the grass vegetation cover. At the time of observation, height growth of grandiflora was much greater than the others, including Acacia auriculaeformis, Leucaena leucocephala, and Calliandra species (Sumarna and Sudiono, 1974).

At the Indian Grassland and Fodder Research Institute (IGFRI), S. grandiflora was compared with Leucaena leucocephala, transplanted to grass plots at 1x1 m spacing and cut 3 times at intervals of 7, 7, and 17 weeks. By the third cut, grass yields were depressed under grandiflora compared to grass alone; combined dry matter grass yields from the 3 cuts were approximately the same whether or not grandiflora was interplanted, but grass yields were increased by about 40% when leucaena was interplanted. Data was not given on legume yields, nor was it indicated that they also were cut (Gill and Patil, 1981).

Subsequently, S. sesban was tried as an intercrop with napier grass varieties under fertilized and irrigated conditions. In one comparison of leguminous shrubs sown at 50 cm spacing, total green fodder yields of 2 cuts taken in the establishment year were (in Mg/ha) 68.4 for leucaena, 71.0 for sesban, and 33.5 for desmanthus (Gill and Patil, 1983). In another comparison of legume species, sesban, leucaena, and Stylosanthes hamata were sown in rows 75 cm apart between rows of hybrid napier grass varieties. Mean legume fresh yields (total of 2 cuts) were (in Mg/ha) sesban 23.4, leucaena 19.0, stylo 14.3. Grass yields were highest under leucaena; no statistical analysis was given (Gill et al., 1983).

Sesban has also been interplanted with Brachiaria mutica around pondbanks at IGFRI sites where rainfall is 900-1250 mm/year (Patil, 1979). Sesban is a good choice for such environments since it would survive seasonal fluctuations in the pond water level. In the situation reported, an estimated total yield of 32.5 Mg/ha fresh legume fodder could be obtained in 4 or 5 cuts per year.

Intercropping with perennial sesbanias.

A cropping systems research experiment using S. sesban was carried out in Maharashtra, India (Desai and Bhoi, 1982), where legume forage shrubs and trees were interplanted with cereals. Sesban was compared with Sesbania grandiflora, Leucaena leucocephala, and a Desmanthus species at row spacings of 1.0, 1.5, and 2.0 meters, all spaced at 25 cm within rows and given NPK fertilizer (75 kg/ha N as urea). The legumes with their millet intercrop were sown in August and the first cut was taken after 3 months; thereafter, a second cut 6 weeks later was followed by 9 cuts at monthly intervals. Millet was harvested 3 months after sowing and was followed by a wheat intercrop. At first, during the intercropping stage of the experiment, the legumes were cut back to half of their height or half the height of regrowth; subsequently, intercropping was discontinued and a uniform cutting height of 90 cm above ground was adopted (the desmanthus was cut at 60 cm height). Vigorous growth of sesban tended to suppress intercrop yields relative to the other legumes, and the wider row spacings using the least competitive legume (desmanthus) were favorable to higher grain yields and, therefore, higher immediate economic returns.

Intercropping studies with sesbanias have been carried out at IGFRI, and summary results have been published (Patil, 1979; similar data was also given in Patil et al., 1981). In one trial, sesban was compared to Leucaena leucocephala in a rainfed situation where seedlings were transplanted to rows 2 m apart at the start of the monsoon rain season, and intercrops of sesame, pigeon pea, and groundnut were grown. Green fodder yields of the first cut after harvest of the intercrops (the interval from planting was unspecified) were 12 Mg/ha for sesban and 2.3 Mg/ha for leucaena. Sesban yields were slightly depressed in the presence of intercrops (9.6-11.0 Mg/ha), but there apparently was no significant difference between yields of the intercropped species in the presence or absence of sesban.

In another experiment (Patil, 1979), sesban given 20 kg/ha N and 60 kg/ha P205 was intercropped at "wide" (unspecified) spacing with rainy-season fodder crops (sorghum, millet, maize, cowpea, or guar) which received no fertilizer. Following the harvest of the fodder intercrops and the first cut of the sesban in October, wheat given N-P205-K20 at 60-60-60 kg/ha was intercropped, with a second cut of sesban taken in March. The data is shown in Table 1. Green fodder yield from the two cuts of seban grown without intercrops totaled 23 Mg/ha, which was equivalent to the mean of total fodder production from intercropped sesban plus rainy-season fodder crops. When intercropped, sesban's yields were reduced and averaged 49% of solecrop yield at cut 1 and 39% at cut 2. The intercropping scheme provided an average wheat yield of 3 Mg/ha grain and 4.5 Mg/ha straw. In the case of the non-legume fodder intercrops such as maize, millet, or sorghum, the balance of protein and carbohydrate components of the intercropping scheme would probably be of greater value to ruminants than the legume alone.

In a second intercropping experiment for fodder production under irrigated conditions at IGFRI (Patil, 1979), control plots of sesban sown alone in rows 50 cm apart yielded 23 Mg/ha, v.s. 27.6 Mg/ha when sown in 25 cm rows. When the sesban in 50 cm rows was intercropped with a wheat-millet-sorghum scheme (not precisely specified), sesban yields were only slightly reduced, but total green fodder yields of sesban+millet+sorghum were 52 Mg/ha, more than double that of sesban alone. In addition, wheat was harvested for grain. When the sesban was excluded, total fresh fodder yields (millet+sorghum) were reduced by about 10 Mg/ha, and there probably was a greater loss in protein yield.

In a third experiment (Patil, 1979), S. grandiflora was grown with an intercrop of wheat. Figure 1 illustrates that wheat yields were reduced only slightly by including the legume, while an additional 10 Mg/ha of fresh fodder was obtained.

S. grandiflora has been included with other N-fixing trees in an experiment in W. Samoa intercropping trees with taro (Cable et al., 1983.) The trees were pruned for mulch material which was applied to the taro, and after harvest of the taro, they were allowed to grow for fuelwood. Results of the work have yet to be fully reported.

Yield trials and management of perennial sesbanias.

A description of the occurence and management of S. sesban in the Deccan of India was given in an anonymous (1924) bulletin from Bombay entitled "Shevri as a fodder crop." The crop had long been grown in certain districts because of its adaptation to "malai" lands, areas below flood level along rivers. There, and in irrigated lands nearby, farmers managed sesban either as a single stand or as an intercrop with sorghum, maize, or Lablab purpureus. One suspects that sesban occurred naturally in these areas as it does in similar environments in Africa, because transmittal along waterways is a common method of seed dispersal for many Sesbania species (Trivedi, 1955). However, in the districts of the Deccan under discussion, high land management intensities would indicate that stands were deliberately sown.

On malai lands, seed was sown broadcast. The first cut for fodder was taken at 3-4 months growth when, according to the bulletin, side shoots were trimmed. The main stalk was eventually cut back to a height of about 125 cm; about 4 cuttings were made in each year. When grown as an intercrop, growth rate was said to be slow until after harvest of the maize or sorghum, at which time the sesban was topped at 125-150 cm height to encourage side branching. Fodder obtained was said to be of high quality, and lands capable of growing this crop were rented out at high rates.

Another cropping pattern described was in rotation with sugarcane, where sesban provided not only fodder but fuelwood for processing cane. After one year in cane, lands were cropped to a main season rice crop sown in June and intersown with rows of sesban. The sesban was subsequently harvested for fodder until, 17 months after sowing, it was harvested for fuelwood before planting the next crop of cane. An acre (0.405 ha) of sesban thus grown could maintain two bullocks and a cow for a year. "Opening" of the soil by the deep roots of sesban and a heavy fall of leaf litter were cited as additional contributions to this rotation. The carryover ability of this crop to provide fodder during hot weather in India when fodder becomes scarce was also noted (Anon., 1924; Patil, 1979).

On saline lands, sown in rows 125 cm apart, cuts could be made every 1.5 months after an initial 3 month establishment phase. An average of 2130 kg/ha was taken in each of 23 cuts over the first 3 years (an average of 48 days/cut), cutting at 125 cm height (Anon, 1924).

The bulletin also reported a cutting trial in which sesban was sown in rows 90 cm apart at a seeding rate of 30 lb/acre (34 kg/ha) and irrigated frequently. The first cut was made at 39 days, followed by a cutting regime of 9-10 cuts per annum, varying from 20-49 days between cuts. Cutting near ground level was found to be detrimental, so a cutting height of 2.5 ft (76 cm) was adopted. Yields are recorded in Table 2. The fodder from sesban compared well in quality with alfalfa (Medicago sativa) grown on adjacent plots; sesban had slightly less nitrogen (2.78% at 5% moisture content v.s. 2.98% for M. sativa) and a higher fiber content.

Mungicar et al. (1976) in Maharashtra, India, reported the yield response of S. sesban in comparison with 7 other crops grown with varying fertilizer nitrogen application rates. Sesban was sown in rows 25 cm apart and was first cut 10 weeks after planting, followed by cuts at 5-week intervals at an unspecified cutting height. Harvested sesban material had 15-22.5% dry matter containing 2.9-4.3% nitrogen. For some reason not explained in the report, sesban was given high N application rates, up to 640 kg/ha during its 280-day growth period in each of 2 years of the experiment. These apparently excessive rates were of doubtful value with sesban and the other legume tested, Medicago sativa. Dry matter yields of sesban in years 1 and 2 of the experiment were 6 and 9.1 Mg/ha at zero N applied, and 8.3 and 10.6 Mg/ha at the highest rate. Dry matter accumulation rates varied from 21.4

to 36.8 and averaged 29.8 kg/ha/day.

Subsequently, Gore and Joshi (1976) focussed on sesban in another experiment in Maharashtra to determine productivity under various cutting intervals and fertilizer sources. They were interested in the effect of these treatments on yields and on the extractability of leaf protein. S. sesban var. picta was sown at a rate of 65 kg/ha in rows 30.5 cm apart in October, and given either inorganic NPK fertilizer, farmyard manure plus superphosphate (FYM-P), or no nutrients (control). In the first year, irrigation water failed in May so the trial was abandoned and sown again in October; thus the authors presented 3 sets of data, 2 for the cutting interval treatments (3, 4, or 5 cuts) during 7 months of growth during both years, and one for the total 12-month period of the second year, in which 3 additional cuts were taken at each interval level.. Fertilizer was applied basally and in splits 15 days after cuts, with the splits measured in such a way that all cutting interval treatments received identical total amounts. The NPK treatments received a total of 110-110-55 kg/ha N-P2O5-K2O in year 1 and 140-140-70 in year 2; FYM-P (P as P2O5) were 39,000-80 kg/ha in year 1 and 44,000-100 kg/ha in year 2. Cutting intervals were 35-40 days, 49-52 days, and 60-65 days. Growth rates calculated for the fertilizer treatments (Table 3) indicate an apparent cumulative benefit from fertilizer applications in the second year; while mean dry matter accumulation rates remained the same for the control, rates increased for the other treatments. Effects of the FYM-P treatment did not become significant until year 2, but benefits from NPK applications were immediate. Total yields under the different cutting frequencies were similar in year 1 but in year 2 the shortest interval was significantly more productive. Nitrogen content of the dry matter varied from 3.3 to 4.1% but was not affected by treatments, so protein extractability varied with the dry matter yield.

Sato (1966) reported results with some green manure species evaluated in Thailand, where S. sesban was outstanding when a growth period of around 10 weeks was possible. At 55 days from sowing, yields were about 25 Mg/ha fresh weight, similar to Crotalaria juncea. This latter, an annual, then began its reproductive phase where leaf growth ceased, whereas sesban continued to grow. Sesban's later flowering and indeterminate growth contributed to its superior yield over the longer term, but since fast, early growth is valued in green manu[illegible] bean was selected as the best short-term green manure in the study.

Rather less data is available on yields of S. grandiflora than for S. sesban. In Java, grandiflora was compared to other green manure candidates in rows 30-40 cm apart, and gave the highest fresh yield after a 6-7 month growth period: 55.27 Mg/ha (data of Koch and Weber, 1928, quoted by Coster, 1939).

In an intercropping experiment in India, researchers recorded total green fodder yields for S. grandiflora of 13.6 Mg/ha from 11 cuts taken over 14 months, v.s. 16.8 Mg/ha for S. sesban, 17.3

Mg/ha for desmanthus, and about 10 Mg/ha for leucaena (Desai and Boi, 1982; Desai et al, 1983). Cuttings may have been too frequent for grandiflora.

In the Chiang Mai region of northern Thailand, S. grandiflora was tested among candidate species (mostly grasses) for intensive cut and carry fodder production for small dairy operations (Holm, 1972). All entries were sown in rows 50 cm apart, cuttings were taken at an unspecified height every 6 weeks, and topdressings of NPK fertilizer were made after cuts so that these nutrients were apparently not limiting factors. Dry matter yields of grandiflora during the 2 years of the trial were 7.2 and 5.7 Mg/ha/year, the lowest productivity of all entries; yields of most grass species were 2-3 times higher. However, grandiflora had a higher level of digestible protein (18%) and starch equivalent (60%) per unit of dry matter than any of the 12 other plants tested, and provided the third highest amount of total digestible protein: 1,062 kg/ha/year (Holm, 1973).

S. grandiflora is widely used as a margin-planted cut-and-carry fodder source in Java and in India. Kareem and Sundararaj (1967) estimated that 40-50 trees planted 1.5 m apart along irrigation channel bunds could provide enough fodder for a milch cow throughout the year. Up to 9 pickings/tree/year could be taken after the plants reached a height of about 2.3 m in 6 months from sowing, and each tree was said to yield about 3 kg fresh leaves per pick. They recommended that trees "should be carefully picked of the leaves lest severity of picking harm the plant."

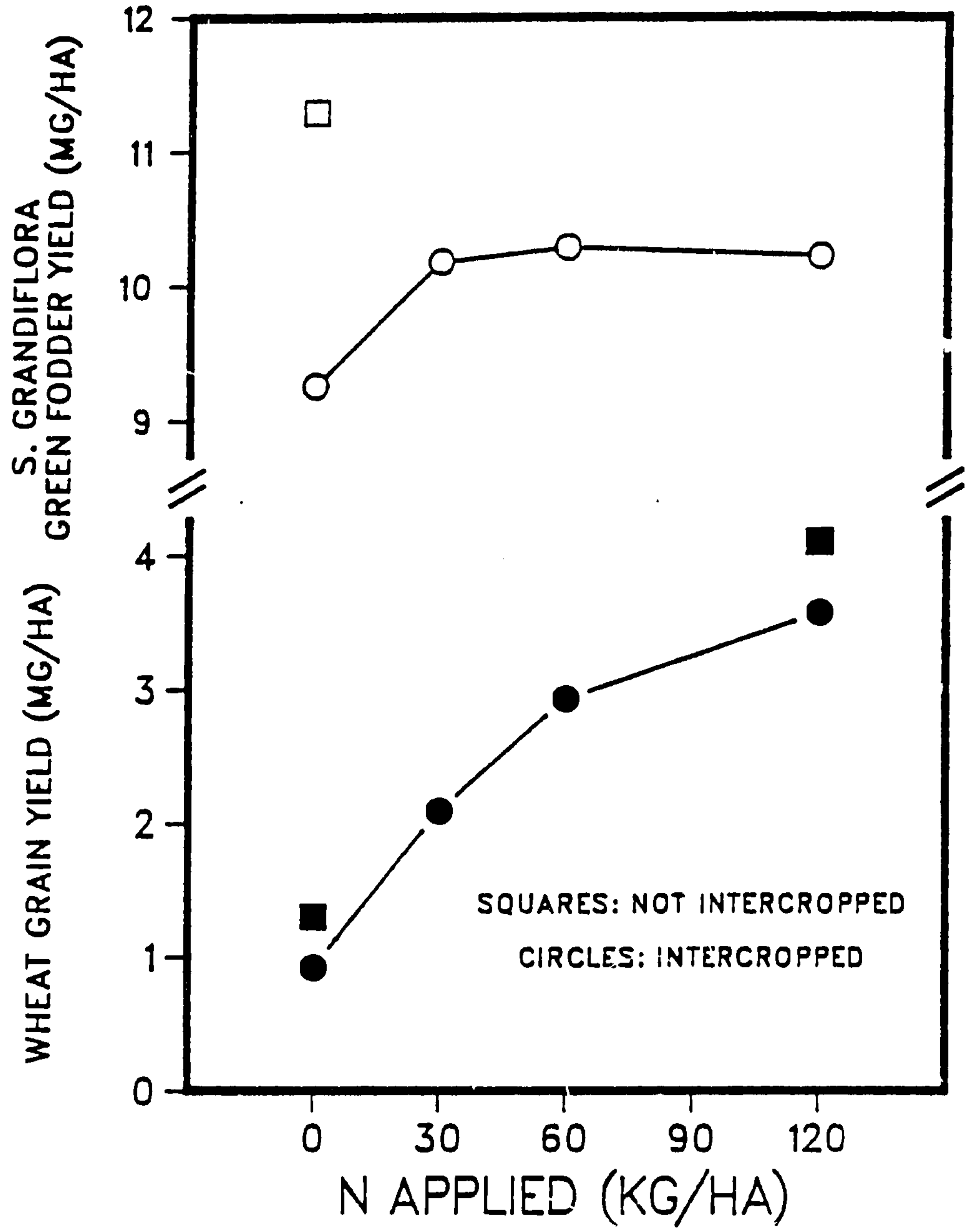

Figure 1. Yields of Sesbania grandiflora and wheat in an intercropping scheme. From data of Patil & Gill in Patil, 1979, Table 4.

Table 1. Production of fodder and grain by <u>Sesbania sesban</u> and intercrops. From data of Patil & Gill given in Patil (1979).

Intercrop	S. sesban Green Fodder Yield: Cut 1	Cut2	Total	Intercrop Green Fodder Yield	Total Fodder Yield	Wheat Grain Yield
	Mg/ha					
-	10.88	12.98	23.16	-	23.16	-
sorghum	5.22	5.16	10.38	14.28	24.66	2.99
maize	4.02	4.92	8.94	17.94	26.88	2.69
millet	4.92	4.69	9.61	12.25	21.86	2.66
guar	6.49	5.39	11.88	9.52	21.40	3.56
cowpea	5.86	5.09	10.95	11.05	21.00	3.23

Table 2. Experimental yields of <u>Sesbania sesban</u> at Manjri, India, 1917-1921 (Anon., 1924)

Year	Number Cuts	Cutting Interval: average	range*	Green Fodder Yield: average	year total	rate
		days		kg/ha		kg/ha/day
1	10	34	20-49	1314	13,141	38.6
2	9	39	19-84**	1371	12,343	35.1
3	10	32	18-48	1666	16,647	52.1
4	8	34	27-45	1201	9,607	35.3

* cuttings were being fed fresh to cattle, so were made by plot as needed and not by schedule.

** 84-day interval to allow for change from cutting at 4 inches height to cutting at 30 inches.

Table 3. Effect of fertilizer on yields of *Sesbania sesban* (from data of Gore & Joshi, 1976).

Treatment	Average dry matter accumulation rate		
	3, 4, or 5 cuts		5 to 8 cuts
	Year 1	Year 2	Year 2
	kg/ha/day		
no fertilizer	19.6	19.0	17.6
farmyard manure + P	24.7	29.9	28.3
NPK fertilizer	26.8	36.6	35.1

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3. SESBANIA SPECIES AS GREEN MANURES.

Sesbanias are generally known as green manure crops, but their use as such, like the practice itself, is for the most part confined to Southeast and South Asia. Evidence of their deliberate management for green manuring--or any other purpose--in Africa is almost nil. Varieties of S. sesban have in recent years been incorporated into agroforestry development projects in Rwanda (T. Zeuner, personal communication) and are said to be grown among bananas in Uganda (Karani, 1983), but their specific use as green manures in these situations was not mentioned. The only published information on sesbanias for soil improvement in Africa concerns experimental use of S. rostrata as a green manure in Senegal.

Sesbanias as green manures in Asia.

Green manuring has been practiced widely in Asia, where fields are often small and their management intensive. Many Asian cropping systems are based on rice cultivation, and because of the ability of Sesbania species to grow in heavy soils, withstand waterlogging and flooding, and tolerate soil salinity, they are often the preferred green manure crop in these systems. Dhaincha is the common name of the species used in India, often designated as S. aculeata but revised to S. bispinosa. The name S. cannabina is also sometimes given for the annual sesbania used in Asia, particularly in China. Occasionally, the perennial S. sesban has been mentioned as a green manure crop. Since there is no Asian taxonomy for Sesbania, the accuracy of nomenclature in many of the agricultural reports is suspect.

As green manure (GM), sesbanias are grown and plowed under in the same field in rotation with the crop to be benefitted. They may also be used as green leaf manure (GLM): green matter cut and brought from elsewhere to the field for burial. Green leaf manure may be partitioned from the top growth of nearby GM crops, or it may be from plants deliberately grown for GLM production on field borders, paddy bunds, and miscellaneous areas. The perennials *S. sesban*, *S. grandiflora*, and the annual *S. speciosa* are among species often planted to be used as GLM.

Intercropped green manures.

As a method of economizing time and space in intensive cropping patterns, green manure legumes are sometimes intercropped. Techniques of interplanting and intercalating *S. cannabina* for green manuring rice have been developed in southern China (FAO, 1977). The sesbania is sown (70-90 kg/ha) in nursery plots having an area about 1/50th of the area to which they are later transplanted. The nursery plots are well fertilized with phosphate and organic manure (night soil or compost) and are sown in late March or early April, when temperatures are above 12C. When the plants are about 10 cm higher than the spring rice crop, which is then in grain-filling stage, they are transplanted to the rice field in rows 2-3 m apart, spaced at about 30 cm within the rows. After they recover from transplant shock and increase in height to from 90-150 cm, the sesbanias are topped to stimulate branching and an additional dressing of compost and P is applied. Several weeks after transplanting the legumes, the spring rice is harvested; after an additional 2 weeks growth, the sesbania is incorporated into the soil along with 50-60 kg/ha ammonium sulfate, the field is flooded, and within a few days the "late" rice crop is transplanted to the field. The practitioners claimed that green manuring in conjunction with mineral fertilizers not only increased yields but at the same time reduced the fertilizer N requirement of the rice crop.

Similar practices were reportedly taken up in North Viet Nam during the 1965-1970 period, as described by several authors in volume 27 (1971) of the English language publication, Vietnamese Studies. There, S. cannabina, or dien thahn, was either transplanted as above or sown directly into the rice fields before harvest of the "fifth-month" rice crop in May, to be incorporated during plowing operations in preparation for the summer crop to be harvested in October. In Thanh Oai district, this method was used on 1/3 of the rice fields. In the Ngo Xuyen cooperative, various methods of utilizing sesbania were tried; although sesbania was said to be easier to grow than azolla, the traditional green manure, its cultivation as an intercrop was thought to compete with rice (the timing and management were unspecified), and the presence of woody taproots was said to make plowing difficult.

A variation on management of sesbania as an intercrop in rice in Viet Nam has been reported by Nao (1979). Mounds are made at a spacing of 100 x 50 cm in between the lines of rice plants, with the tops of the mounds emerging from the water. From 3 to 5 seeds are sown in these hills about 6 weeks before harvest of the spring rice. An estimated 8-10 MT/ha of resh green manure can thus be grown for incorporation before the second rice crop is transplanted in July. Alternatively, if a second rice crop is not grown, the sesbania is allowed to mature and is harvested for fuelwood in October, yielding about 15-20 Mg/ha of stems, about 10 Mg/ha of root, and about 400 kg/ha of seed collected during maturation of the crop. This option has the advantage of providing a fuelwood crop should rains be inadequate to support a second rice crop. In the area of the Red River delta where this method was developed, population densities are high and demands for locally available fuelwood make such an alternative attractive.

Sesbanias have occasionally been used as intercrops in upland cropping systems. Van de Goor (1954) reviewed pre-WWII research in Java in which a number of legumes including _S. bispinosa_ and _S. sericea_ were compared. When intersown 6 weeks after sowing maize, legumes did not depress maize yields. In Bihar, India, bispinosa intersown 45 days after sowing maize and grown for 60 days before incorporation resulted in following wheat yield increases varying (with levels of P applied to the legume) from 22-38% over control (Shukla and Sinha, 1970).

Singh and Sinha (1962) reported a series of experiments in which _S. bispinosa_ and other species had been sown simultaneously in the same row as maize and then incorporated for following wheat. Their objective was to find a green manure which could be so sown as to not intefere with interculture operations, which could be incorporated using little more effort than that normally required to cultivate maize stubble preparatory to sowing wheat, and which would improve yields. The results of the first year's trial, shown in Table 1, indicate that _S. bispinosa_ smothered the maize, although wheat yields were doubled. In subsequent experiments, they concentrated on legumes which competed less with the maize than _S. bispinosa_ (and, it was also found, _Crotalaria juncea_) did; they focussed on the slightly slower-growing perennial _Sesbania punctata_ (a variant of _S. sesban_) and on _Aeschynomene americana_.

Sesbanias are used as an intercrop in banana plantations in Taiwan, where bananas are replanted each year and grown as an annual crop because of the seasonal threat of typhoon winds. The sesbania is sown in the interrows at the time of transplanting the banana starts. Later, the legume topgrowth is cut and used as mulch around the developing pseudostems. The weed control provided in the interrow zones by growing the legume is valued in addition to its other contributions (M.L. Lin, personal communication).

Margin-planted green leaf manures.

In parts of South and Southeast Asia, farmers make use of field borders and miscellaneous areas to grow crops to provide green leaf manure. _Sesbania_ species are particularly well adapted to margin plantings in rice and other lowland irrigated cropping systems because of their tolerance of waterlogging. Their tolerance to salinity may also be an advantage in deltaic areas and where soils of bunds concentrate salts by evaporation. S. grandiflora is widely planted in margin situations with adequate size and permanance. Smaller bunds or waterway banks serving as subdivisions between fields may be removed and restructured during cropping cycles and thus are not appropriate for perennial species. However, in parts of Indonesia (D. Ivory, personal communication), S. grandiflora is managed on bunds as an annual. It is sown during development of one crop, allowed to put on growth during periods when competition effects are not critical, and pulled up and incorporated into the soil during field preparations for the crop to be sown during the next rainy cycle. This species has rapid initial growth and is thus suited to such use.

Sesbania speciosa has been extensively used for margin planting in India, particular in Madras State (now the state of Tamil Nadu) (Chari, 1957). Originally from Africa, seed collected in Kenya was probably sent from England's Royal Botanic Gardens at Kew to Sri Lanka, from whence it was introduced to Madras. Popularization of this plant in Madras was achieved through vigorous extension efforts begun in Tanjore District in 1952. A massive campaign was created involving articles extolling the crop in popular farming magazines (e.g. Chintamani, 1954; Vedantam, 1955; Rajagopalan & Pawar, 1958), support of government agricultural officials at many levels, creation of village Agricultural Associations, "farmer's day" demonstrations at experiment stations, slide shows in rural theatres, and government purchase of speciosa seed to promote its increase (Ali, 1959). Having demonstrated to themselves the efficacy of green leaf manuring with the plant in experiments in 1947-48, the officials began promoting speciosa with the distribution of about 140 kg of seed. By 1956, about 1 million acres in Tanjore were margin-planted with speciosa as a result of these efforts (Randhawa et al., 1961).

S. speciosa seeds can remain viable for long periods: 15 year old seeds obtained by the author from USDA were viable. Their seed coats are impermeable to water and therefore scarification is required for germination. We found that concentrated sulfuric acid soaking times of at least 40 minutes were necessary for this species, and that 60-90 minutes were not detrimental. Rao and Venkatesan (1965) found that hot water treatment of 10 minutes at 80 C was effective; probably a shorter duration at 100 C could be found which would eliminate the need for a thermometer. They also got good germination by carefully pounding seeds mixed with sand. S. speciosa should be inoculated when sown in any new area. The publications cited on its use in Madras did not mention inoculation or nodulation, and it is probable that appropriate Rhizobium strains were present in that area. We have found that in Hawaii S. speciosa does not effectively nodulate with strains which nodulate other sesbanias. This may explain the data given by Sahu (1965) for green leaf manures being compared in India's Orissa state, where speciosa GLM had only 2.24% N compared to S. bispinosa with 4.95% N.

Nurseries for S. speciosa should be kept from waterlogging for at least the first three weeks of seedling development, during which time the plants are not yet able to adapt to this stress. Seedlings should be at least 30 days old, preferably 45 days old, at time of transplanting, an operation which can be accomplished by hand at close spacing on a hectare field's borders by two laborers working one day (Rao and Venkatesan, 1965).

Yields for S. speciosa planted on margins are in the broad range of 2000 to 6000 lbs fresh material for a one-acre field (Randhawa, 1961), but the range of 2,500-3,500 lbs given by Rao (1965) may be average (1 lb/acre = 1.12 kg/ha). Yields for solid stands grown 3-5 months are generally reported as greater than 50,000 lbs/acre fresh weight; even as high as 100,000 lbs/acre has been claimed (Randhawa et al., 1961).

Green manures in crop rotations.

Much of the literature on green manuring (Evans et al., 1983) dates from periods in which traditional cereal varieties followed the green manure crop. During the last few decades, introductions of high yielding varieties (HYVs) have often increased cropping intensities, and the availability of inorganic N fertilizers has made fallow periods, legume rotations or green manuring less mandatory, resulting in unfavorable declines in soil fertility and physical properties. Gill (1978) characterized the HYV rice-wheat rotation in the Punjab as "exhaustive," citing among other evidences that Zn applications had become routinely necessary, and stating that where rice was grown continuously, soil physical conditions deteriorate; sowing *S. bispinosa* as a green manure between wheat harvest and rice transplanting was recommended. Smil (1984) also noted deteriorations of soil structure in China due to intensified cereal cropping. Decreased sowing of legumes, less frequent green manuring, and use of crop residues for fuel rather than incorporating them into the soil were conditions associated with increased use of organic N and implicated as causes of recent widespread occurrences of potassium and micronutrient deficiencies.

Early estimates of the yield response of rice to green manuring may have been low because of the low yield potentials of traditional varieties. Thus Panse et al. (1965) suggested a plateau in yield response of rice to GLM applications in excess of 5000 lb/acre (5600 kg/ha) fresh material which, assuming 20% dry matter, would represent an application of approximately 45 to 55 kg/ha N. Recent research conducted using HYV rice in rotation with green manures indicates that the yield benefits of green manuring are sizeable.

The data of Dargan et al. (1975) shown in Figure 1 illustrate a fairly typical HYV rice yield response to inorganic N, with a tendency for yield increases to level off in the range of 80-120 kg/ha applied N. The amount of N contributed by the 67-day-old green manure crop was not estimated, but it produced a rice yield equivalent to 30 kg/ha inorganic N.

Bhardwaj et al. (1981) also compared rice response to green manures with and without added inorganic N (Figure 2). Their data indicate a generally linear response to added N and a tendency for yields to level off at higher rates regardless of the N source; the response to green manuring was similar to 60-80 kg/ha fertilizer N. Khind et al. (1982) (Figure 3) found that green manures grown 2 months were equivalent to 60-90 kg/ha inorganic N. These experiments illustrate that green manures can supply much if not all of the N needed for moderate to high yields of N-responsive rice varieties, and that a combination of green manure with inorganic N can be highly beneficial to following crops.

Timing is important in including green manures in crop sequences. N.T. Singh et al. (1981) found sharp increases in dry matter and N content of green manure legumes between the 5th and 7th weeks of growth. Likewise, the data of Khind et al. (1983) (Figure 4) show that S. bispinosa N content increases many-fold during the second month of growth (from 8 to 58 kg/ha), and then doubles again during the third month of growth. Subsequent upland rice yields increased with the growth duration of the preceeding green manure crop. The yield response to green manure N was similar to the response to fertilizer N, but it appears from a comparison with the unfertilized control that the effect of the 30-day green manure crop involved more than just the N contribution of the tops.

The timing of green manure incorporation in relation to planting the beneficiary crop may also be of critical importance. Beri and Meelu (1979) compared inorganic N after fallow with S. bispinosa GM incorporated 0, 10, or 20 days before transplanting rice, with or without supplemental N fertilizer (Fig. 5). Where inorganic fertilizer was not applied, the beneficial effect of transplanting soon after incorporation of the green manure was evident. Supplementing the green manure with inorganic N masked the response to the rapidly released green manure N; indeed, fertilizer N applications seemed superfluous here, and most N so added was probably lost from the system.

Sesbania bispinosa has also been used to some extent as a green manure for wheat, especially in irrigated areas of northern India. In such situations--and especially so in rainfed areas--consumptive water use by subsidiary crops in rotations may have critical effects on availability of irrigation water or of soil moisture for the main crop. For example, Allen (1915) reviewed the effects of experimental green manuring on wheat crops between 1884 and 1903 in Maharashtra, India, and concluded that >90 cm total monsoon rainfall was needed in order to include the green manure crop. Moreover, 25-40 cm of rain were needed between legume incorporation and planting of wheat to obtain yield increases due to green manuring in that system. Because of such considerations, there has been research recently on the water requirements of green manure crops. Gaul et al. (1976) grew S. bispinosa for 10 weeks under different irrigation regimes and concluded that for North India summer conditions, 60-65 cm of irrigation was required for a green manure crop grown between the harvest of wheat and the next rainy-season crop. In the same region, N.T. Singh et al. (1981) compared S. bispinosa, guar, and cowpea under irrigation regimes designed to create different levels of water deficit. Cowpea showed the greatest efficiency in dry matter and N production per unit of water expense, but was the most sensitive to yield reduction under drier soil water regimes, whereas dry matter yield of sesbania and guar was relatively constant. N content of the tops of these crops grown for 7 weeks increased with increasing water applied in the general range of 80-100 kg/ha N, with cowpea approaching 120 kg/ha N at the highest irrigation level. Cumulative water expense by the crops was lowest (29-36 cm) for cowpea and highest (32-38) for sesbania.

Results of using S. bispinosa with wheat show reasonable yield increases. Chandnani (1954) compared legumes grown 7-8 weeks and found that sesbania increased grain yields 27% over control yields of 1.66 Mg/ha; guar (36%) and Crotalaria juncea (35%) were also effective. Ballal et al. (1968) found that sesbania green manure grown 6-7 weeks produced wheat grain yields 58% greater than control (1.58 Mg/ha), and increased wheat N and K uptake compared to other green manure species tried. M.P. Singh and Sinha (1964) reported a series of experiments comparing different sources of green leaf manure with S. bispinosa green manure for wheat. GLM applications at 9.19 Mg/ha fresh material (using _Glyricidia_, _Calotropis procera_, _Indigofera tinctora_, or _Sesbania punctata_) generally tripled wheat yields over control yields. They estimated that 0.25 ha of _S. punctata_ would provide sufficient loppings for GLM for 1 ha of wheat, and that under local conditions applying GLM was more economical than growing a green manure crop. They had previously (Singh and Sinha, 1962) obtained a tripling of wheat yields when _S. bispinosa_ was grown as a green manure, compared to wheat following fallow.

Table 1. Yields of green manure legumes intercropped with maize, and their effect on maize and following wheat yields (Singh and Sinha, 1962).

Legume Intercrop	Legume fresh yield	Maize grain yield	Wheat grain yield
		Mg/ha	
Crotalaria juncea	11.5	2.04	1.88
Sesbania bispinosa	24.8	0.55	2.41
Sesbania speciosa	2.3	2.30	1.34
Aeschynomene americana	5.8	2.40	1.63
none (maize alone)	-	1.67	1.23
CD 0.05		1.05	0.48

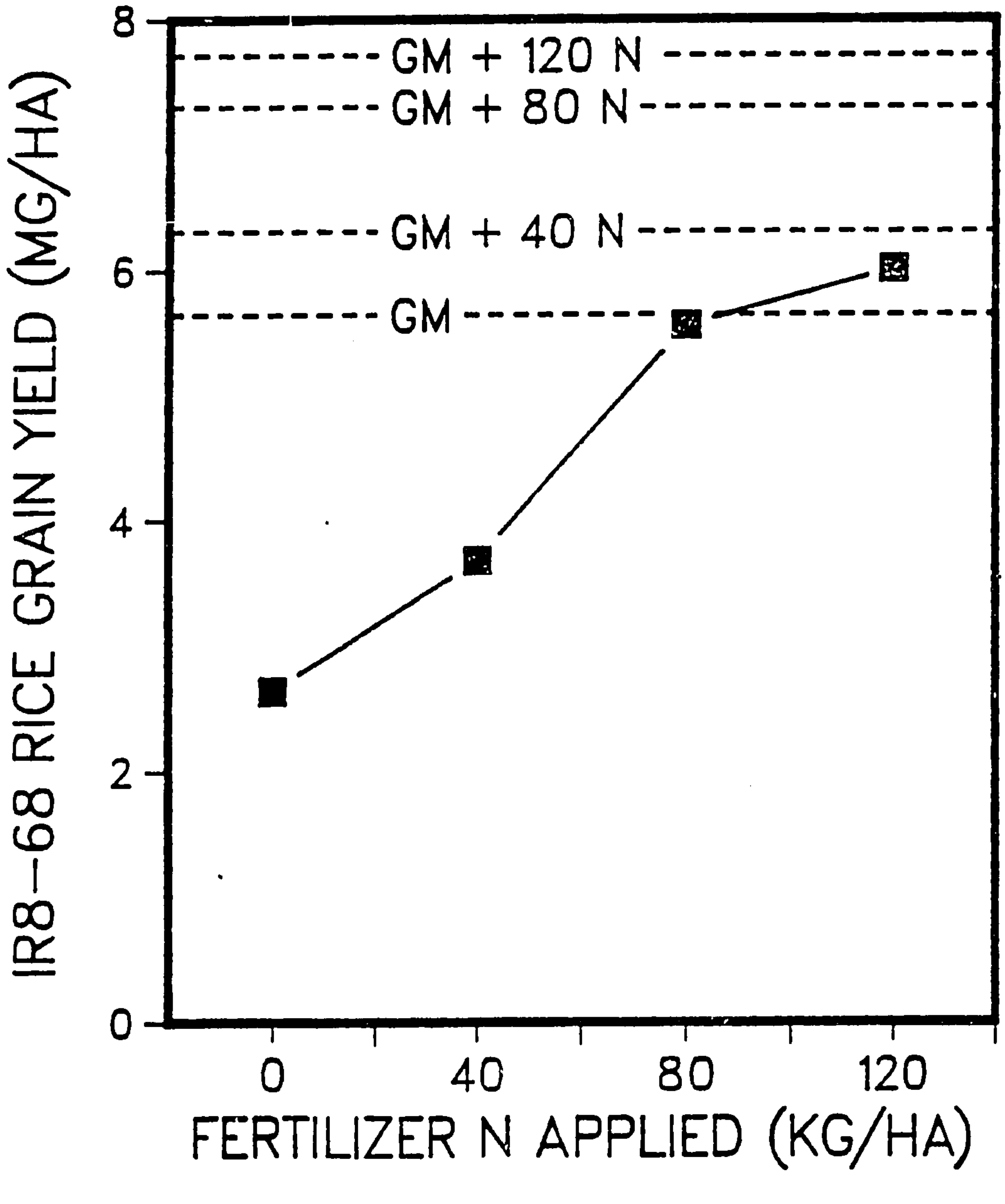

Figure 1. Rice yield response to Sesbania bispinosa green manure (GM) and to inorganic nitrogen fertilizer (N), both alone and in combination. Squares represent N fertilizer alone. From data of Dargan et al., 1975.

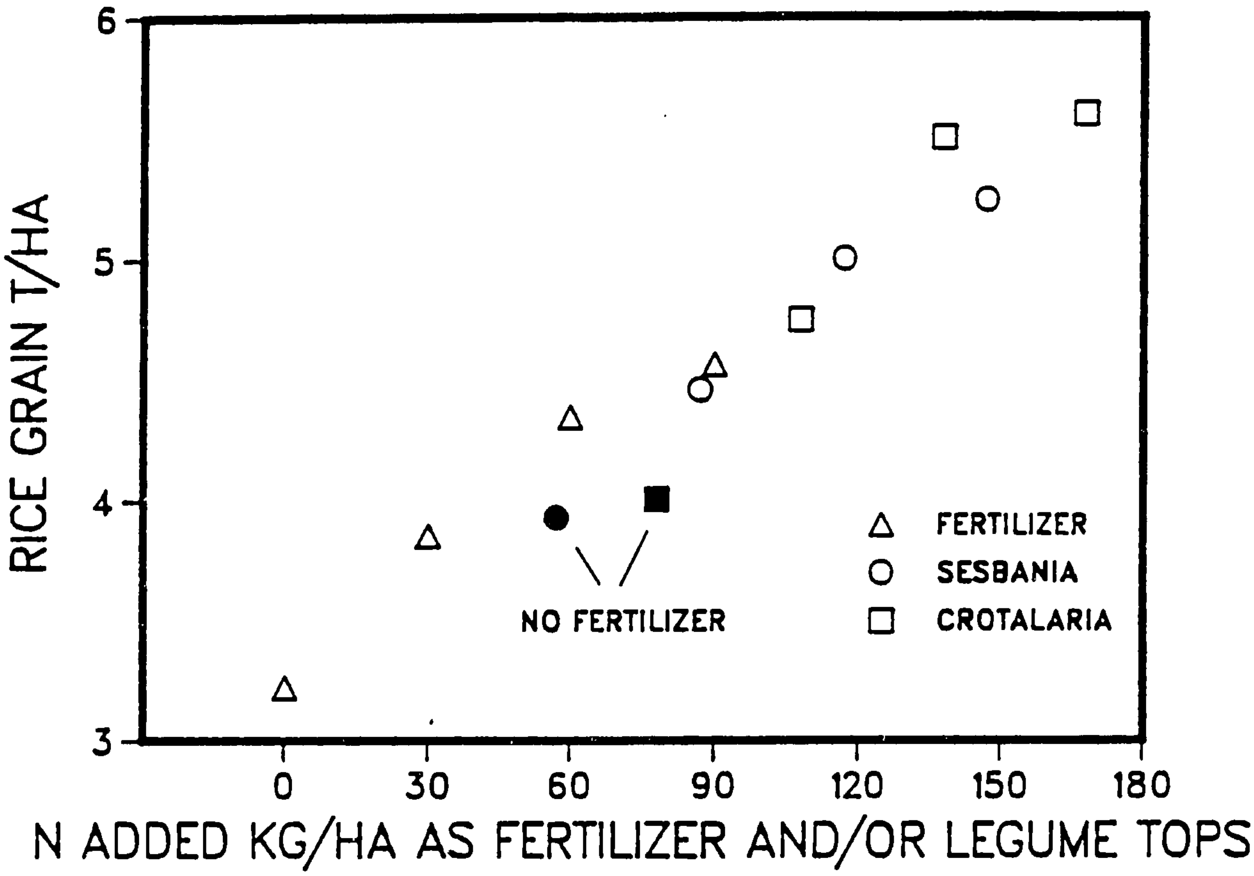

Figure 2. Rice yield response to inorganic nitrogen fertilizer applications with or without a preceeding _Sesbania bispinosa_ or _Crotalaria juncea_ green manure crop, compared to green manuring alone. From data of Bhardwaj et al., 1981.

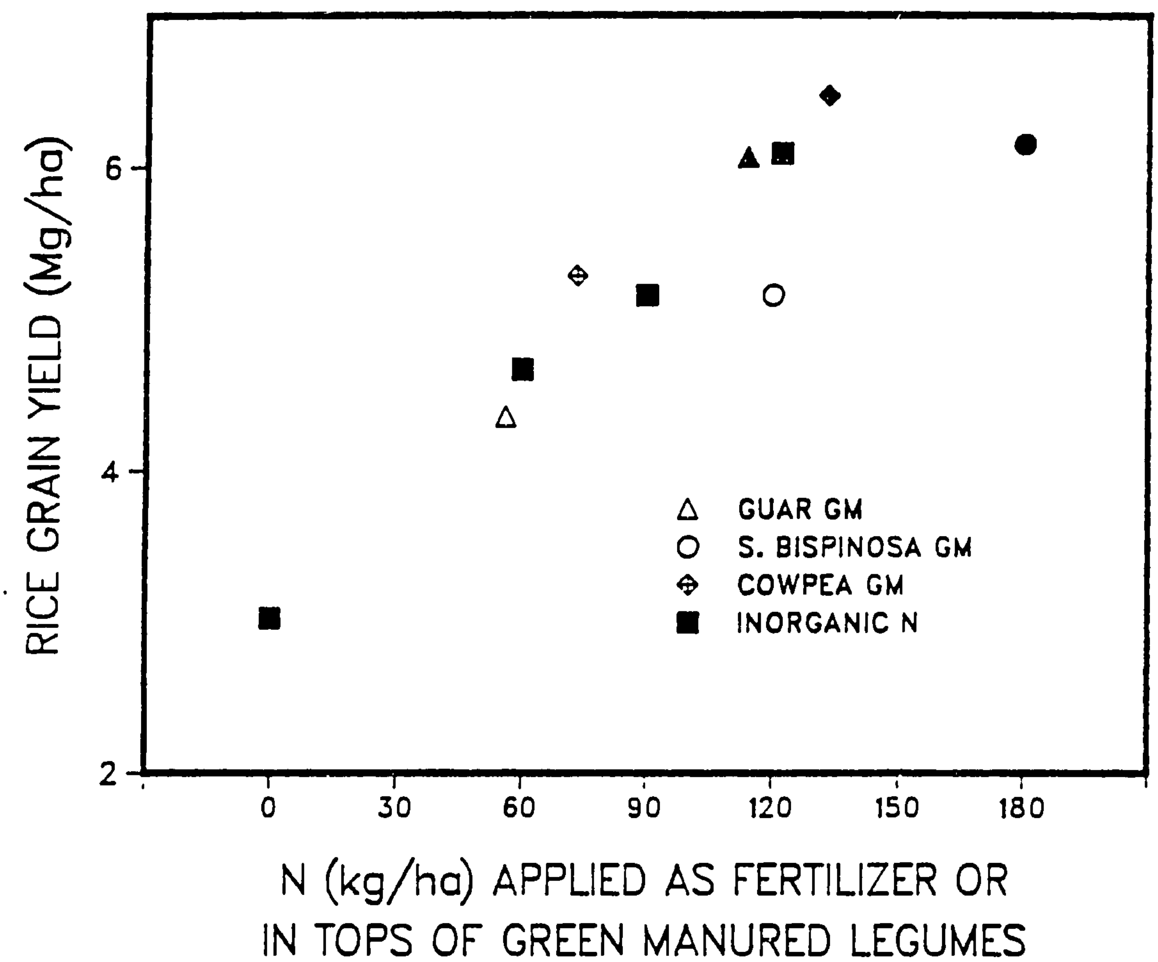

Figure 3. Rice yield response to inorganic N fertilizer and to green manures alone (open symbols) and supplemented with 60 kg ha^{-1} inorganic N fertilizer (solid symbols). Green manure crops were *Sesbania bispinosa*, *Cyamopsis tetragonoloba* (guar), and *Vigna unguiculata* (cowpea).

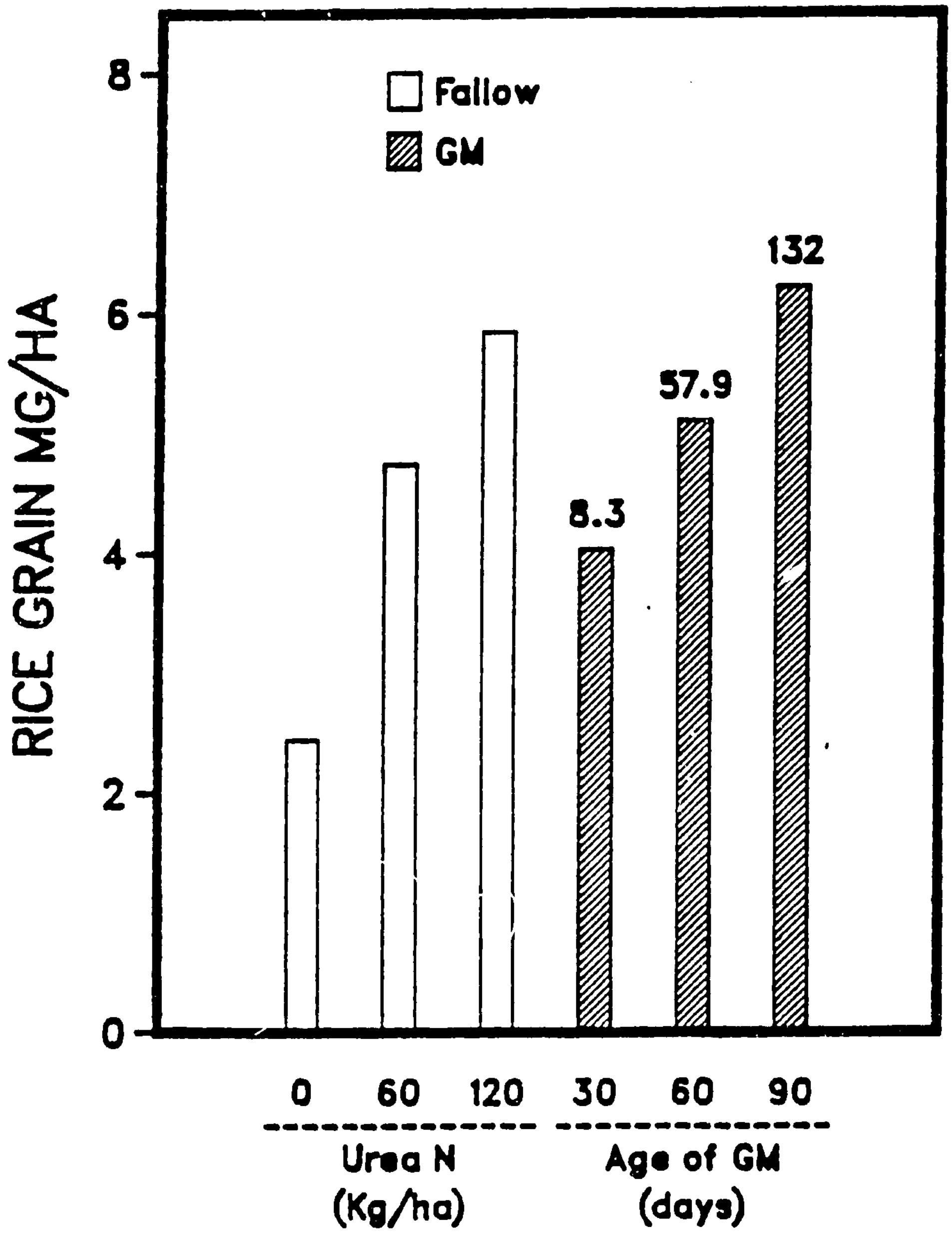

Figure 4. Yield of rice following Sesbania bispinosa green manure (GM) grown for different durations before incorporation, compared with rice receiving inorganic nitrogen fertilizer after fallow. Values at tops of bars are the N contents of the legume above-ground growth, kg ha^{-1}. From data of Khind et al., 1983.

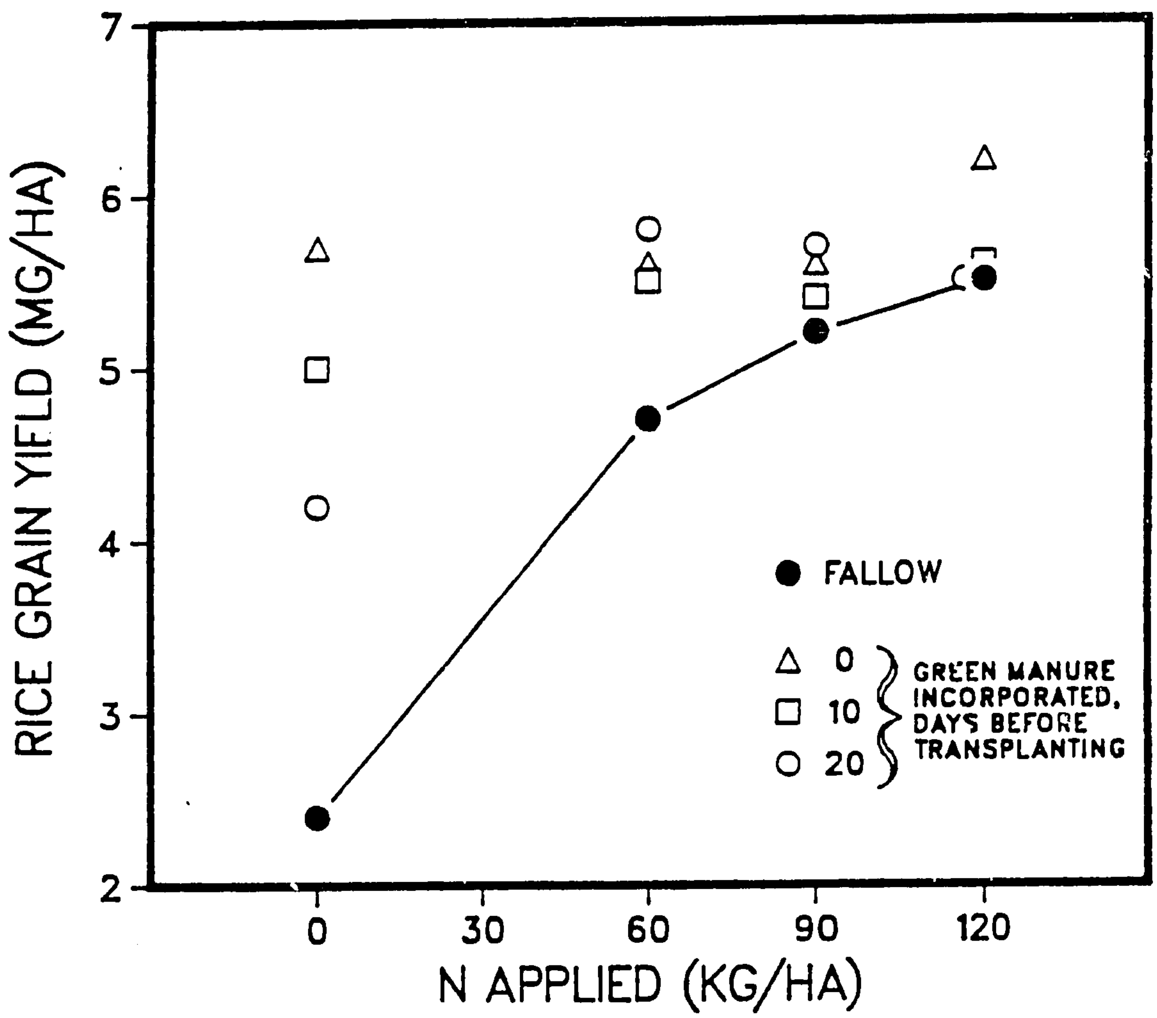

Figure 5. The effect on rice yield of various time intervals between the incorporation of *Sesbania bispinosa* green manure into the soil and the transplanting of rice. Green manuring is compared to fallow, with and without supplemental inorganic nitrogen fertilizer applications. From data of Beri and Meelu, 1979.

Sesbanias as green manures in the Americas.

Use of sesbanias in the Americas has been more limited than in Asia, if the scarcity of published literature on the subject can be taken as an indication. The annual species native to North America, S. exaltata (formerly S. macrocarpa) has been used as a green manure crop in Arizona (Parker, 1972) and was popular in Southern California (Pieters, 1927; USDA, 1922). In the Imperial and Cochilla valleys in California and the Yuma and Salt River Valleys of Arizona, exaltata was used as a cover crop in citrus orchards and a green manure for winter truck crops; the species grows well in hot midsummer weather where humidity is low (USDA, 1935, 1967). On cotton lands in lower California, the response to sowings at seed rates of 45 kg/ha during midsummer were dramatic in the luxuriant growth of 6-8 week old crops; growers of cotton, lettuce, onions, and melons were at one point enthusiastically expanding areas sown to sesbania for its ameliorative effects on the soil (Hodges, 1930). At that time, 12-14 inch (30-35 cm) moldboard plows were used to turn under the crops if the plants were not much-branched; a chain on the plow was useful to drag down thick stands, and discs were used to level the heaviest or much-branched stands before plowing.

Inda (1939) reviewed uses of Sesbania species in southwestern USA and Mexico, and Peregrina (1965) in Mexico evaluated a species as an intercrop in maize. De Datta (1981) mentioned its use in rotation with rice in Texas, increasing rice yields by 20% or more. In the western coastal state of Sinaloa in Mexico, exaltata (sometimes called S. sonorae in Mexico, where it occurs in Sonora and other states) has been used as a green manure on tomatoe-growing lands (Pieters, 1927). Compared to cowpea, exaltata yielded more, required less cultivation to control weeds, and was less susceptible to pests when grown during the hot, summer rainy season. Pieters' informant stated that because sesbania fields could be flooded, weeds and a number of insect pests could thereby be killed.

S. exaltata has been mentioned among other summer legumes as a candidate summer cover crop and green manure in USDA literature (USDA, 1935 and 1967), and specifically as a crop for date palm gardens (USDA, 1919). It was considered for the Columbia Basin in northwestern USA, but was rejected as not adapted to the cool night temperatures there (Morrison, 1981). Throughout most of its range this species sets seed rather quickly and over a long period, flowering from March to October in Arizona (Parker, 1972), and its potential to become a weed is almost certainly the reason why in some areas of the southwest it is no longer used for green manure. Seed coat dormancy, or "hardseededness," contributes to the problem of containing the plant to its place in cropping sequences, since even if care is taken to plow under the crop before seed maturation, some of the original seed may remain in the field to germinate later unless appropriate scarification technique had been performed to assure complete and uniform germination. Pieters' informant mentioned that improper, or better, unfortunate timing of plowdown operations such that they were delayed by wet soil conditions could result in the crop becoming woody, and the same jeopardy would apply to incorporation of the crop before seed maturity. Parker stated that once it had been used as a cover crop in the Yuma region, it appeared in 70% of the cotton fields in the area. Its propensity to colonize ditch banks encourages the transmittal of seed along irrigation waterways.

Agronomic evaluations of <u>S. exaltata</u> in the Americas are rare. Williams and Doneen (1960) used it as a summer green manure on a clay loam at El Centro in the Imperial Valley, California, comparing it with sudan grass green manure in an attempt to improve infiltration. It was still vegetative and 1.25 m high when incorporated in mid-August after 52 days growth. Average dry matter yield over two seasons was 3430 kg/ha (2.36% N). Williams (personal communication), using the non-legume as a comparison, calculated that the sesbania fixed an average of 65 kg/ha N each season. Using sesbania as green manure in summers 1 and 3 of the experiment did not improve infiltration, but using the non-legume in all three years did. The authors did not report the effects of the green manures on the subsequent crop, sugar beets, but G.F. Worker, Jr., in a personal communication commented that the N contribution of sesbania was not observed to benefit sugar beet yields.

On the other hand, Matlock and Aepli (1948) found that barley yields over 5 years were improved by sesbania (presumably exaltata) green manure at Mesa, Arizona. Sesbania was slightly more effective than Vigna aconitifolia, Crotalaria juncea, and V. unguiculata green manures, producing barley yields one-third greater than the control, but in that environment it appeared that Cyamopsis tetragonoloba (guar) was superior, increasing barley yields 58% over the control. In California, guar had been shown to yield more than S. exaltata, with a fresh yield of 32.1 Mg/ha compared to sesbania's 27.6 Mg/ha for 52-day summer crops on heavy soils in the Imperial Valley (Anon., 1931).

Recently, Day and Ludeke (1981) evaluated exaltata for growth on desert soil compared with copper mine overburden, overburden plus tailings, and tailings. Sesbania and blue lupin (Lupinus hirsutus) grew equally, but best growth was obtained with alfalfa (Medicago sativa).

Exaltata has also been studied in Florida, USA, particularly in regard to its status as a host of nematodes (see the section on pests and diseases). Overman (1969) observed that chrysanthemum yields were benefited by a preceeding crop of S. exaltata, but only when the soil had been fumigated before sowing the legume; in the absence of fumigation, Desmodium tortuosum had the greater effect on yields. Soffes et al. (1980), testing summer cover crops on a fine sand soil in a crop rotation scheme, found very low yields of sesbania, probably due to severe nematode infestation and inability to compete with weeds. Similarly low yield and N content data were reported from the same research program in Florida by Prine and Mislevy (1983). However, Soffes (personal communication) concludes that the species has potential as a green manure for wet soil sites in Florida.

Seed of S. exaltata is available from Dessert Seed Co. of El Centro, CA, which sells seed obtained from a grower in Yuma, AZ; sales volumes have been low in recent years, less than 1 MT per year (W.J. Bray, personal communication). According to R.R. Harp of Pacific Southwest Seed and Grain, Inc., in Yuma, use and production of exaltata over the past 15-20 years has fallen to almost nothing. Seed production is difficult because of shattering; seed must therefore be harvested before drying and the pods spread on tarps to dry before cleaning (Harp, personal communication).

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4. SESBANIA SPECIES FOR SOIL RECLAMATION.

Plants which are able to tolerate stresses caused by excesses of certain soil elements, and deficits of others, are able to colonize problem soil sites and are, therefore, important in stabilizing and in reclaiming these lands. Mining is one way in which man creates severely disturbed land areas, and we have found two instances in which Sesbania species have been considered as elements of pioneer vegetation for mining sites. In W. Australia, a Sesbania species was found useful for stabilization of lands affected by iron ore mining (Martinick & Atkins). In Arizona, U.S.A., S. exaltata was evaluated on desert soils altered by additions of copper mine overburden, tailings, or their combination, and was found to grow as well as Lupinus hirsutus but not as well as Medicago sativa on these sites (Day & Ludeke, 1981).

A far more extensive group of problem soils are those containing excessive levels of soluble salts (saline soils) and exchangeable sodium (sodic soils), or their combinations, such that growth of most crops is inhibited. Sesbania bispinosa is extensively grown on such soils in India. Soils with these combined properties are often termed saline-alkali soils, having exhangeable-sodium percentage (ESP) >15 and electrical conductivity of the saturation extract (EC_e) >4 mmhos/cm. The soil reaction is often moderately to strongly alkaline. In more recent terminology, these soils are identified as saline-sodic soils. In the following, we will generally employ the terminology given by the authors of cited discussions.

Sesbanias as green manures for salt-affected soils.

Green manures are of particular value in providing organic matter to soils having impeded drainage, very thin organic soil horizons, and poor soil structure; these conditions are common in saline-alkali soils. In the Indo-Gangetic Plains of northern India, there are 2.5 million hectares of salt-affected soils (Abrol & Bhumbla, 1979), and the use of Sesbania bispinosa as a green manure is considered an effective element of soil reclamation strategies. These strategies also include soil leveling, applications of gypsum providing sulfate anions for acidification and calcium cations to displace sodium on the soil exchange complex, leaching with irrigation water to move displaced sodium ions down through the soil profile, and growing salt tolerant crops (Uppal, 1961; Agarwal & Gupta, 1968; Abrol et al., 1973; Mehta, 1983).

Articles in popular magazines directed to Indian farmers have often stressed the value of using S. bispinosa in rotations on saline and alkali soils (Srivastava et al., 1973; Dargan et al., 1975; Third et al., 1979). The plant is known in India as "dhaincha" and is often identified, archaically, as S. aculeata. (In the following discussions, "sesbania" will refer to S. bispinosa.) Agarwal (1957) advised farmers that rice yield increases of 37% could be obtained using green manure, of 97% using gypsum, and of 173% using both combined. Upadhyay & Singh (1976) observed that low yields of grain crops in the first year of a reclamation program were improved considerably in the second year after a sesbania green manure crop. Dargan et al. (1975) showed that on an alkali soil (pH 9.2) sesbania green manure was equivalent to application of 80 kg/ha N, increasing rice yields 50% over rice following a fallow period. Shirwal & Deshpande (1977) demonstrated that fertilizers alone could not solve the problems brought about by soil salinity: rice given only NPK yielded 0.92 Mg/ha, but when soils were reclaimed with 2.5 Mg/ha gypsum and green manuring with sesbania, yields jumped to 3.75 Mg/ha Mathur et al. (1973) also showed significant rice yield increases resulting from green manuring saline-alkali soils in Rajasthan. It is not known exactly how extensively _S. bispinosa_ is used as a result of these promotions, but Chela & Brar (1973) visited villages in the Ferozepur district of Punjab state and observed that the crop was used on half of the total cropped area.

Effects of added organic matter are important to reclamation of these soils, as demonstrated on a saline-sodic soil where the responses to either sesbania green manure, or powdered _Argemone mexicana_ leaf, rice straw or farmyard manure (FYM) incorporated at 5.6 Mg/ha, or gypsum at 12.5 Mg/ha, were rice yield increases of 57, 70, 49, 53, and 23%, respectively (Misra, 1976). This indicates that gypsum alone is sometimes not as effective as organic matter. Green manures (sesbania, _Crotalaria juncea_, _Vigna_ spp.) grown in a soil having pH 8.5 resulted in following wheat yield increases averaging 47% over controls not green manured (Ballal et al., 1968). Frequently however, combinations of organic matter and gypsum provide the best amendment, as Mendiratta et al. (1972) showed in a factorial experiment with gypsum, FYM, and sesbania green manure: wheat yields were higher with the 3 treatments combined than with any single or 2-treatment combination. Jauhari & Verma (1981) described the reclamation of a soil judged "practically non-productive" using gypsum (8.5 Mg/ha) or pyrite (6.5 Mg/ha), paddy straw, and sesbania green manure; rice given adequate N-P-K-Zn fertilizer yielded 0.7 Mg/ha grain in the first year of reclamation and 3.13 Mg/ha in the second year. Lignite fly ash is another possible soil amendment, and in a pot experiment proved as effective as gypsum in lowering soil pH and increasing rice yields; added sesbania green leaf manure alone or in combination with the ash significantly increased yields (Mahalingam, 1973). Sulfur has been shown to be an effective alternative to gypsum on a calcareous saline-alkali soil, and again, the greatest soil improvement and resulting increases in wheat yields were associated with combinations of sulpher applications and sesbania green manuring (Somani & Saxena, 1981). Press mud, a byproduct of sugar manufacture, is another organic amendment which has been shown of value applied alone or in combination with sesbania green manure (Shetty, 1975; Dhawan et al, 1961).

Physical site preparations are also important in saline and alkali soil reclamation. Leveling assures even leaching and eliminates ponding. In lands with high water table and subject to waterlogging, trenching may be effective to encourage drainage.

Such methods combined with deep plowing and S. sesban as green manure have been recommended for preparing lands for afforestation with fast-growing trees less tolerant of salts and waterlogging (Sheikh, 1974).

Leaching is an important element of reclamation. Dhawan et al. (1961) described an effort on a "white alkali" soil ($NaCl$- and Na_2SO_4-dominated) and a "black alkali" soil (Na_2CO_3-dominated), both approximately pH 10. From 45-60 cm of water was applied in 5-7 weekly irrigations before transplanting rice, which received an additional 75 cm of irrigation and 38 cm of monsoon rainfall during its growth period. The authors pointed out that where initial soil conditions did not permit vigorous growth of a green manure crop, green leaf manure could be brought from nearby. In their experiment, varying green leaf manure application rates beginning at 4.5 Mg/ha fresh material were compared or combined with farmyard manure, press mud, or distillary waste (pH 4.5-4.9).

Ameliorative effects of sesbania green manure.

Sesbania has been used for saline soil reclamation in coastal areas of the north China province of Liaoning (about 40 degrees north latitude), where it was believed that the dense plant cover reduced soil water evaporation, thereby preventing upward movement of salts and their concentration at the soil surface (Jen et al., 1965; Anon., 1966). The crop was observed to increase soil porosity, and the added organic matter promoted soil aggregation. In North America, Williams & Doneen (1960) grew S. exaltata to improve water infiltration rates in soils of California's Imperial

Valley, but found that it was not as effective as sudan grass. Compared to these few non-Indian references, research reported on soil reclamation in India is voluminous, which is not surprising considering the extent of irrigated land area in India and the agricultural importance of alluvial and problem soils in the Indo-Ganges region.

High levels of sodium in soils depresses carbon mineralization and formation of organic matter by depressing the cellulolytic fungal and bacterial populations active in this process. CO_2 evolution and the formation of stable end-product organic matter constituents such as humins and humic and fulvic acids is reduced, with a resulting decrease in the solubilization of $CaCO_3$ (Malik & Farooq, 1979; Malik & Sandhu, 1975; Malik & Haider, 1977). N-mineralization during decomposition is reduced under saline and alkaline conditions (Singh & Rai, 1975). Increasing salinity also increases ammonia volatilzation and loss when N-rich soil amendments such as green manures are incorporated into soils (Malik & Farooq, 1979; Venkatakrishnan, 1980). The latter author compared sodic and reclaimed soils incubated with added sesbania material and found extensive N volatilization from the sodic soil between the 2nd and 9th (concluding) week of the experiment. It is possible that under field conditions, in the presence of rice roots, such losses would be reduced.

While losses of N from low C:N ratio materials may be greater than from high C:N materials, the former were shown to be more effective in reducing exchangeable sodium percentage in a calcareous sodic soil (N.T. Singh, 1974). Sesbania plant material reduced an initial ESP of 91 by 36% to 58 over a 10-week incubation period, whereas barley straw only resulted in a 10% reduction.

Somani and Saxena (1981) monitored microbial populations in a field experiment comparing gypsum and sulfur with or without organic matter amendments in a calcareous saline-alkali soil. They found that total microflora counts increased to a greater extent when sesbania green leaf manure was added than when farmyard manure, poultry manure, or rice husk were used, and they attributed this to the rapid decomposition and high Ca content of the legume. The combination of sesbania and sulfur produced the greatest improvement in soil properties, and the effects of the two amendments were additive.

Both green manuring and gypsum favorably affect saline-alkali soil structure and therefore the soil's hydraulic conductivity, resulting in leaching of displaced sodium ions into deeper soil layers (Yadav & Agarwal, 1959). Where plant roots are present, CO_2 secretions by them enhance dissolution of calcium salts and the displacement of sodium with divalent ions (Kanwar et al., 1965). Yadav & Agarwal (1961) compared the effects of gypsum and sesbania green manuring, and their data showed the complimentarity of the two amendments, the former facilitating base exchange reactions and the latter improving physical characteristics and, particularly after the second year, increasing soil N and organic matter.

Uppal (1955) found that stem and leaf juices of sesbania seedlings were quite acidic, with a pH around 4.0 during the first few weeks of growth, later rising to 7.0 after 10 weeks of growth. The implication of these results is that younger sesbania crops may be especially effective in reducing soil pH when green manured, but we are not aware of research done to investigate this.

Tolerance of sesbania to saline and alkaline conditions.

Tolerance to saline and alkaline conditions is common in the genus *Sesbania*. Gillett (1963) observed that African species are segregated in habitat according to the degree of salinity in the edaphic environment. This tolerance may be related to water requirement, since species with greater adaptation to drought might be expected to encounter increasing salinity as soils dry or as seasonal land-surface waters evaporate. Gillett pointed out that some species (*S. sesban*, *S. keniensis*) prefer to grow beside running streams, while others inhabit margins of slightly saline lakes (*S. goetzii*) or seasonally flooded shallow pans, growing in zones across salt gradients (*S. somalensis*).

In Hawaii, most endemic *Sesbania* species are halophytes, growing in sand dunes and corraline soils very near the seacoast, often where they constantly encounter salt spray. Char (1983) observed that populations of the endangered *S. manaensis* growing in the margins of a pond declined after a man-caused disturbance which resulted in a dilution of salinity in the pond waters. These observations of Char and Gillett suggest that some sesbanias may be obligate halophytes, while others such as *S. sesban* and *S. bispinosa* may owe their wide distribution to a facultative tolerance of saline and alkaline conditions.

Saline-alkali soil reclamation in India involves chemical and physical soil amendments and the growth of salt tolerant crops. Rice is frequently a pioneer crop in these situations: it is shallow rooted and can be grown with only shallow, preliminary leaching of salts; it is transplanted with a root system already developed in more favorable soil enviromnents in nurseries; 6-week-old rice seedlings can tolerate electrical conductivities of up to 14 mmhos/ch (Dahiya et al., 1981). Continued leaching during the growth of a rice crop may allow for more deeply rooting crops such as sesbania, berseem clover (*Trifolium alexandrinum*), wheat, or barley to be sown subsequently. Like rice, sesbania may also be transplanted to avoid salt sensitivity in the seedling stage, and pH in excess of 9.5 can thereby be tolerated (Uppal, 1955).

As Singh & Rai (1972 a, b, c, 1973, 1974) have shown in pot culture with artificially created levels of salinity and alkalinity, legumes such as *S. bispinosa* and *Melilotus alba* suffer decreased germination percentage, root growth, shoot growth, nodulation, and nitrogen fixation as sodium and bicarbonate levels increase; plant respiration increasec with sodium. In their study, alkaline conditions were generally more detrimental to growth parameters than were saline conditions, and were less amenable to amelioration by applications of P fertilizer. Gill

(1979) also showed that soil alkalinity adversely affected growth in *S. bispinosa*. Relative to the more pronounced detrimental effects shown by cowpea, the resistance of sesbania was associated with its higher protein content. Although it is a salt- and alkaline-tolerant legume, perhaps moreso than *M. alba*, *S. bispinosa* is less tolerant than grasses such as *Diplachne fusca* (Malik, 1978) or *Bracharia mutica*. Bajwa & Bumbla (1971, 1974) compared the latter with *S. bispinosa* and found the grass to be relatively sodium-tolerant, the legume relatively sensitive; having a low root CEC, the grass absorbed Na in excess of Ca, while the legume had high root CEC and absorbed more calcium. From growth responses in soil with adjusted ESP, they determined that 50% yield reduction occurred at ESP 55 for *B. mutica* and ESP 37 for *S. bispinosa*. In severe situations sesbania may require some soil amendment before it can be grown. For example, Abrol & Bhumbla (1971) obtained low yields (2.08 Mg/ha fresh material) of dhaincha on an unamended saline sodic soil, but with gypsum applications of 7.5 or 15 Mg/ha, legume yields increased to 16.12 and 17.44 Mg/ha.

The soils of experiments reviewed here wherein positive response to green manuring with sesbania were obtained had pH's in the range of 8.5 to 10. Khan & Awan (1967) analysed soils from a farm in Pakistan where a *S. bispinosa* crop was either luxuriant, patchy, or had failed. Total soluble salts in the surface 23 cm soil horizon were 0.43, 1.39, and 3.15%, respectively, and the higher salt levels were enriched in NaCl and Na_2SO_4. Jen et al.

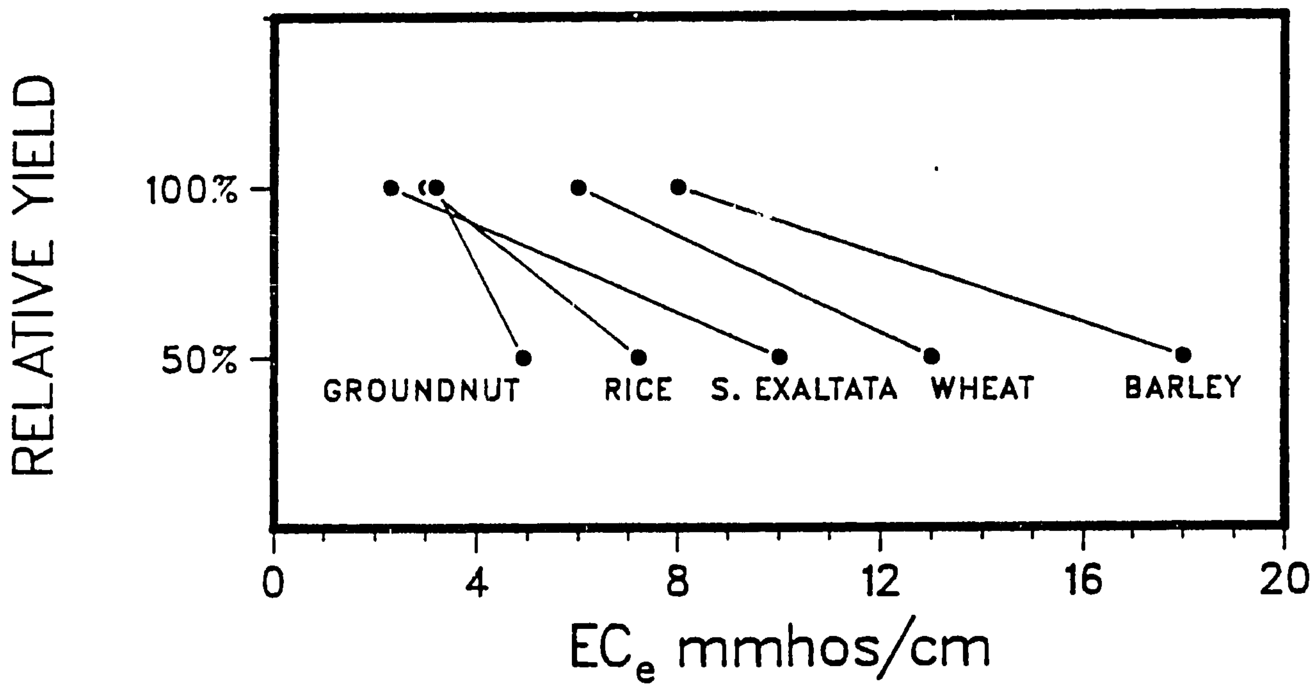
(1965) stated that *S. sesban* tolerated salt concentrations of 0.42-1.04% at seedling stage, and 0.92-1.39% toward maturity. Dutt et al. (1983) showed that *S. sesban* seedling growth almost doubled when an alkaline soil pH was reduced from 8.4 to 7.9 by sulfur application. *S. sesban* was found less tolerant of saline irrigation water (3.5 g/l salts) than *Cyamopsis tetragonoloba* (Ahmad & Niazi, 1977). Sinha (1982) found *S. sesban* seed germination inversely related to increasing salinity, alkalinity, and water stress, but judged a germination response of 20-56% to be moderately good when obtained under conditions other than extreme water stress (>-10 bars) or high alkalinity (>pH 9.5). Sesban's germination has been shown to be good in an adjusted range of soil EC_e from 1-8 mmhos/cm (Arshad & Hussain, 1984). These authors also showed that germination of *S. bispinosa* was reduced to 60% at EC_e 10, 33% at EC_e 20, and 25% at EC_e 30 mmhos/cm (Hussain & Arshad, 1984). *S. grandiflora* has been observed to grow well in drained margins of mangrove swamps (soil pH 7.6) in W. Samoa (W. Cable, personal communication).

S. exaltata in N. America has been considered a salt-tolerant crop and was indicated as slightly more tolerant than *Medicago sativa*, but less tolerant than *Trifolium alexandrinum* at high EC_e's: 50% yield reductions of *S. exaltata* were associated with EC_e=10 mmohs/cm, while maximum yields could be obtained at EC_e=2.3 mmhos/cm (Maas & Hoffman, 1977; Ayers, 1977). Some EC_e values for maximum yields and 50% reductions for selected plants are illustrated in Figure 1; for barley and wheat, germination and early seedling growth require EC_e=4 to 5 mmhos/cm (Ayers, 1977). S. exaltata yield responded significantly to the acidification of alkaline (pH 8.3) irrigation water with sulfuric acid on a calcareous soil (Christensen & Lyerly, 1954).

A number of experiments on S. bispinosa's yield and nutrient uptake in response to varying soil ESP and rates and types of soil amendments have been reported by a group at Hissar, Haryana State, in northern India. They have shown that sesbania's dry matter yield decreased considerably below that of maize as soil ESP increased over the range of 2-77%, and, expectably, that increasing ESP increased plant Na content and decreased plant Ca content. Sesbania was able to take up as much as 31% of Ca applied as gypsum, compared to 17% for maize (Poonia & Bhumbla, 1972, 1974a). Increasing rates of gypsum (2,4,6, and 8 me/100 g saline-sodic soil) and of farmyard manure (3,6, or 9% dry matter basis) were found to increase bispinosa's dry matter yield (Poonia & Bhumbla, 1973 b & c). As expected, gypsum was shown to be superior to $CaCO_3$ as a Ca source for sesbania at varying soil ESP's when it was found that labeled Ca uptake from $CaCO_3$ decreased with increasing ESP, but uptake from gypsum did not decrease. Sesbania took up 19-25% of the applied Ca from gypsum, but only about 5% from $CaCO_3$ (Bhumbla & Poonia, 1973), and farmyard manure was not effective in enhancing Ca uptake from $CaCO_3$ (Poonia & Bhumbla 1973c). Similar results were obtained with a non-saline alkali soil given either Ca source at 25-100% of the calculated soil gypsum requirement; sesbania did not increase in yield in response to $CaCO_3$, increased gradually in yield given $CaSO_4$, and was much more efficient in utilizing applied Ca than was barley (Poonia & Bhumbla, 1973a). Various acidifying agents were tried in order to increase solubility of $CaCO_3$, and sesbania yields were generally increased thereby; aluminum sulfate depressed plant P uptake, and while HCl produced the greatest dry matter yield increases, it had the least effect on plant Ca uptake (Poonia & Bhumbla, 1974b). Differing P sources were tried at varying soil ESP levels, and it was found that increasing ESP did not affect the contribution of added P to total P uptake, but uptake was increased by P source (calcium phosphate > sodium phosphate) and rate (50 ppm P > 25 ppm P) (Poonia et al., 1977). A sand culture experiment using nutrient solutions varying in Na and Ca levels corroborated S. bispinosa's sensitivity to increasing Na and its positive response to increasing Ca. Compared to wheat, sesbania translocated less absorbed Na to above-ground plant parts (Poonia & Jhorar, 1974). While some plants are useful in reclamation because they accumulate sodium in their tops so that it may be removed from the site, it appears that this sesbania does not concentrate sodium in its above-ground parts; the implication is that incorporating the tops as green manure will have a favorable effect on the salt balance of the soil.

Abrol & Bhumbla (1979) examined responses of several crops to varying soil ESP brought about as a result of increasing gypsum applications (7.5, 15, 22.5, and 30 Mg/ha). They found rice less sensitive than wheat (contrary to the data of Ayers, above), and rice crops were in themselves quite effective in modifying the soil environment so that ESP levels were reduced over the cropping period. When grown 70 days, S. bispinosa yields without gypsum were negligible, but above the first increment of gypsum, yields were maintained at 40-47 Mg/ha fresh material, over a range of soil ESP from 10 to 50. Their data suggested a decline in sesbania yields above ESP 60 and a 50% yield reduction at about ESP 75. Sesbania was the first crop grown in the sequence of crops tested and was judged tolerant to the initial conditions. Other legumes, grown later in the sequence after the ameliorative effects of previous crops including rice and sesbania, were judged sensitive; they were Vigna mungo, Lens esculenta, and Cicer arietinum.

Figure 1. Salt sensitivity of selected crops (from data of Ayers, 1977).



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5. NUTRITIVE VALUE OF SESBANIA SPECIES.

Sesbania leaves, flowers, pods, and seeds are sources of animal feed and to a more limited extent of food for man.

Uses as food.

Sesbania grandiflora is known in continental and island South East Asia for its large and edible flowers. Raw or lightly steamed, usually after removal of calyx and pistil, they are used as an ingredient of soups, salads, and vegetable dishes. The white flowers are preferred in the Philippines; the red variety are said to be bitter. The smaller flowers of S. sesban, ye`low with purple specks, are sometimes eaten, used perhaps as a decorative or festive ingredient in foods such as omlettes. Young pods of grandiflora are eaten cooked as beans, picked when they are supple and <4mm in diameter. Leaves are also cooked as vegetables. In Sri Lanka, one method of preparation is to cook chopped leaflets with chopped onion in coconut milk, creating a vegetable component of a traditional rice-based meal.

Nutritional studies in India have used leaves of grandiflora in formulations with other vegetable protein sources in experiments with rats, and subsequently in experiments to supplement rice diets in college women (Bai and Devadas, 1973, 1974). Grandiflora leaves were found a good calcium source in rat diets (Devadata and Appanna, 1954). The leaves have also been used in experimental diets for young children in India; they were apparently less palatable than greens of Amaranthus species, being somewhat coarser and more bitter, but leaf vegetables in general had to be offered in mixture with other foods to be accepted (Gopaldas et al., 1973).

Use as leaf protein concentrate sources.

Sesbanias have been considered in India as sources of leaf protein concentrate (LPC). Some of the reported experiments which provided yield data are discussed in the section on yields of perennial species.

Matai and Bagchi (1974) in Calcutta compared legumes including S. bispinosa and found that bispinosa gave quick returns of extracted protein because of its rapid growth over a short period, but like Crotalaria juncea, bispinosa did not regrow well. The authors stated that legumes which could be cut repeatedly at 3-4 week intervals, such as Medicago sativa and Trifolium alexandrinum, seemed preferable and had higher rates of extracted protein production: 7.3 and 4.9 kg/ha/day over 93 and 124 day periods, respectively, with several cuts each, compared to 4.2 kg/ha/day for S. bispinosa over 23 days, or 4.3 over 45 days for C. juncea. The height of cutting was not specified; both of these annual species will regrow after cutting if the cut is 50 cm or more above ground and is taken during a vegetative growth phase, but they may not stand repeated cutting. Experiments in Hawaii have indicated that with some annual sesbanias including S. bispinosa, 2 or 3 cuts may be taken during a summer crop (Evans & Rotar, in preparation).

Several reports on S. sesban as an LPC source have been published as a result of research at Marathwada University in

Aurangabad, India. Gore and Joshi (1976) grew sesban and found 40-52% of its protein N to be extractable, with a production rate of 4.3 kg/ha/day extracted protein when cut every 5-6 weeks. Mungicar et al. (1976) compared sesban with M. sativa and 5 non-legumes under varying N fertilizer rates. Sesban cut 7 times per year had a maximum dry matter production rate of 36.9 kg/ha/day and an extractable protein production rate of [illegible].0 kg/ha/day; M. sativa cut 16 times had about twice these rates. After two extractions (the second with added water), the remaining fibers from the legumes contained 10-17% crude protein, adequate as a maintenance diet for ruminants. Liquor obtained after leaf protein extraction from sesban has been found to be a suitable substrate for fungal growth (Deshpande & Joshi, 1971), suggesting applications in production of antibiotics and fungal or single-cell proteins.

Gore and Joshi (1976) had pointed out that maximim protein extractability from sesban was related to the juice:fiber ratio; more juice resulted in greater extractability. Batra et al. (1976) examined this relationship in greater detail and found that a delay of 4 hours between harvest and processing reduced extractable protein by 12-45% in the plant species tried; this reduction was lowest in sesban and highest in hybrid Napier grass. Sesban's juice:fiber ratio (0.9 v./w.) was comparable to M. sativa's at harvest, but the latter's ratio fell 66% in 24 hours, while sesban's fell only 33%. The related diminution in extracted protein was less in sesban than in other crops tested. The authors also found that extractability was maximum from cuttings taken early in the morning and least when plants were cut at midday.

Plant growth stage also affects LPC yields as demonstrated by Singh and Sharma (1981) growing sesban and two other trees, Madhuca indica and Millettia ovalifolia. Leaves of sesban sampled at pre-flowering (Sept.-Oct.), flowering (Nov.-Dec.), or post-flowering (fruit setting) (Feb.-March) periods had increasing percent dry matter (23.1-25.0-26.98) and decreasing percent total N in the dry matter (3.10-2.86-2.60). Sesban had the highest extractability: the LPC dry matter contained 25% of the leaf dry matter, v.s. 20.7% for M. indica and 17.2% for M. ovalifolia; all had the highest extractabilities in the pre-flowering stage. Extractability in sesban fell to about 23% in the subsequent growth stages, a 9% reduction compared to reductions of 8-12% for the others. These authors also reported lysine and methionine contents for sesban as reproduced in Table 1. Another analysis of sesban LPC reported the amino acids threonine, isoleucine, phenylalanine, lysine, methionine, and triptophan in concentrations of 2.8, 4.65, 15.7, 7.75, 4.5, and 6.75%, respectively (Nazir & Saeed, 1970). Kapoor et al. (1978) have reported on alkanes, alkanols, and sterols found in the leaves, flowers, and pods of S. sesban.

Use as animal feed.

Sesbanias have considerable potential as sources of fodder for animals, particularly the perennial species which being adapted to cut-and-carry harvesting methods are amenable to the integration of fodder production into small farm systems. We are not aware of any research or practice of large-scale production or mechanical harvesting of sesbanias for fodder.

Sesbania seeds have been considered as feeds (see the sections on seed gums and on antinutritional factors), and data on their nutritional analysis is assembled in Table 2. Lacking development of sesbania seeds as gum sources, whereby large amounts of byproduct seed husk and kernel would become available, it seems unlikely that they will become feed sources of any significance.

Leaves of sesbanias are generally considered to be excellent sources of protein to supplement protein-poor roughages in ruminant diets. Nutritive analyses of various species are presented in Table 3. These data are all derived from materials found either in Asia or Africa. Some data on the North American species S. exaltata, occuring widely across southern USA and considered a weed, is presented in Table 4. This annual species has very determinate growth, as indicated by the declines in nutritive qualities. The high Ca:P ratios during the reproductive growth period would be a hazard if such materials were used as a sole feed source.

In general, palatability does not seem to be a limitation. Natural stands of sesbanias in Africa are eagerly browsed by cattle (Gillett, 1963). Endemic sesbanias in Hawaii are browsed by cattle, feral goats, and axis deer. S. bispinosa was judged to be quite palatable to rams in the feeding study of Katiyar and

Ranjhan (1969). _S. sesban_ was stated to be less palatable to cattle than to sheep and goats, which "relish it exceedingly" (Anon., 1924).

Several studies on nutritional values of sesbania fodder have been conducted with small ruminants, and their reports of digestibility coefficients are summarized in Table 5. Katiyar and Ranjhan (1969) and Chinnaswami et al. (1978) both used sheep (rams), and the resulting values for digestibility are quite similar. In the latter study, the young animals averaging 14 kg body weight consumed an average of 3.63 kg dry matter/100 kg body weight/day. This was more than the value of 2.17 kg dry matter/100 kg body weight consumed in the earlier study by adult animals averaging 45 kg body weight. In both trials, animals maintained or gained in body weight.

Chinnaswami et al. found positive N, Ca, and P balances. The fresh material fed contained 2.68% digestible crude protein (DCP) and 9.61% TDN; thus the animals consumed 314 g TDN and 95 g DCP daily. Based on nutritional analysis and digestibility findings, the nutritive value of grandiflora was calculated as (in % of dry matter) CP 16.89, EE 0.61, CF 13.01, NFE 30.52, TDN 61.80, and SE 47.40.

Katiyar and Ranjhan found positive N and Ca balances and a slightly negative P balance; the Ca:P ratio of the material fed was 1.24/0.31=4.0. They found (in % of dry matter) DCP 20, TDN 68, and SE 58.5.

Singh et al. (1980) found somewhat higher digestibility coefficients when feeding *S. sesban* to 6-7 month old Barbari goats weighing 7-9 kg, although in common with the other studies, EE digestibility was low. N, Ca, and P balances were positive. Compared to feeding sesban *ad libidum*, supplementing the fodder with barley grain at approximately 20% of dry matter consumption resulted in increased weight gains, increased deposition of N in tissue, and increased digested N utilization efficiency, while dry matter consumption was equal for both regimes.

Holm (1973a and b), using sheep, found that grandiflora fodder had a digestible protein content of 18% (dry matter basis) and SE 60.

Table 1. Protein analysis of <u>Sesbania</u> <u>sesban</u> leaf protein extract (from Singh and Sharma, 1981).

Growth Stage:	pre-flowering	flowering	post-flowering
	% dry weight basis		
Total N	5.77	5.22	4.96
Protein N	4.62	4.14	3.87
Lysine	1.07	0.88	0.84
Methionine	0.38	0.30	0.22
Ash	17.36	16.24	15.90

Table 2. Nutritive value of sesbania seeds.

Species	CP	EE	CF	NFE	Ash	Ca	P	Ref.
bispinosa	32.7	2.9	10.7	48.7	4.9	0.37	0.59	(13)
"	36.4	6.9	12.1	43.1	1.5			(6)
sesban	21.2	2.6	8.5	60.5	7.2	0.44	0.68	(6)
grandiflora	36.5	7.4		51.6	4.5			(4)
" (tegmen)	17.5	0.8	2.7	65.4	1.3			(14)
cinerascens	21.7	4.8	12.2		2.9			(15)
mossambicensis	32.9	6.2	10.9		1.4			(15)

notes: Grandiflora seed tegmen was 20% of entire seed.
references: (see also preceeding table) (13) Sen and Ray, 1964; (14) Subramanian, 1952; (15) Anonymous, 1921.

Table 3. Nutritive values of sesbania materials.

Species	Fraction	DM	CP	EE	CF	NFE	Ash	Ca	P	Ref.
bispinosa	fodder	18.0	25.1	4.2	23.6	37.8	9.3	1.24	0.31	(9)
"	leaves	24.6	30.3	5.1	18.5	35.4	10.8	1.26	0.30	(9)
"	stem	12.3	15.6	1.9	39.4	35.5	7.6	0.90	0.39	(9)
sesban	fodder	19.7	19.5	3.0	33.0	37.1	7.5	1.42	0.09	(11)
"	leaves		26.0	2.6	14.4	49.4	7.6	1.11	0.27	(6)
"	"		26.5	0.9	12.2	50.4	10.0	2.78	0.43	(6)
"	fodder		17.4	3.0	26.0	38.4	9.3			(1)
"	fodder	31.8	17.5	4.2	28.0	13.2	8.1			(8)
macrocarpa			31.2					0.96	0.33	(2)
cinerascens	herbage		25.5	3.0	13.0	52.4	6.1	0.76	0.40	(12)
grandiflora	leaves	86.6	22.6	2.1	18.4	47.5	9.3	1.10	0.32	(5)
"	"	21.0	33.4	2.6	5.7	46.7	11.6	2.33	0.34	(6)
"	"	73.1	8.4	1.4	2.2	11.8	3.1	1.13	0.08	(4)
"	"	17.1	25.6	4.8	17.8			1.46	0.45	(7)
"	leaves*	16.3	26.0	4.9	17.6	42.8	8.6	1.32	0.47	(6)
"			37.3	5.5	6.4	41.0	9.8			(10)
"	fodder		21.4	3.4	22.7	44.5	8.1	1.52	0.28	(3)
"	pods	91.4	1.6	4.8	32.7	54.4	6.5			(6)
"	flowers	11.1	15.1	1.8	13.2	63.4				(6)
"	"	87.4	1.8	0.6	1.0	8.6	0.6			(4)

note: some values have been rounded to the decimals given.
DM=dry matter, CP=crude protein, EE=ether extract, NFE=N-free extract.
* values are means for leaves picked at various ages during wet and dry seasons.

references: (1) Anonymous, 1924; (2) Bosworth et al., 1980; (3) Chinnaswami et al., 1978; (4) CSIR; (5) Devendra, 1979; (6) Gohl, 1975; (7) Hutagalung, 1981; (8) Kahn, 1965; (9) Katiyar and Ranjhan, 1969; (10) Ranjhan, 1980; (11) C. Singh et al., 1980; (12) Verboom, 1965.

Table 4. Forage quality of *Sesbania exaltata* (from Bosworth et al., 1980).

Growth Stage	DMD	CP	Ca	P	Mg	K	Ca/P	K/(Ca+Mg)
	%							
vegetative	70 a	31.2 a	0.96 a	0.33 a	0.34 a	3.7 a	2.9 b	1.26 a
flowering	66 a	13.9 b	1.02 a	0.16 b	0.29 b	2.3 b	7.0 ab	0.78 b
fruiting	52 b	11.2 b	0.92 a	0.11 b	0.22 c	1.4 c	9.3 a	0.59 c

note: DMD = *in vitro* dry matter digestibility; CP = crude protein. Any 2 means within a column followed by the same letter are not significantly different at 5% level according to Duncan's multiple range test.

Table 5. Digestibility coefficients of sesbania materials as reported in several studies.

Source:	A	B	C
Species:	bispinosa	sesban	grandiflora
Feeding period (d) (prelim., sampled)	15,7	45,7	10,7
Animal:	adult rams	kid goats	adult rams
Dry matter	74.0	69.53	65.65
Crude protein	82.1	80.80	79.03
Ether extract	33.9	13.58	18.24
Crude fiber	63.7	56.13	57.30
N-free extract	75.9	67.82	68.60

references: (A) Katiyar and Ranjhan, 1969; (B) Singh et al., 1980; (C) Chinnaswami et al., 1978.

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6. TOXICITIES AND ANTINUTRITIONAL FACTORS.

A small group of sesbanias may be classified as noxious weeds because they produce toxic seeds. These species are often treated as distinct from *Sesbania*, but conservative treatments of the taxonomy usually place them within *Sesbania* but in the subgenera Daubentonia (*S. punicea*, *S. drummondii*) and Glottidium (*S. vesicaria*). Their placement is still a matter of controversy. *S. vesicaria* is an annual which occurs in the southern U.S.A. from the Carolinas through Florida to Texas. The others are short statured perennial shrubs whose range, with the exception of *S. drummondii*, extends from the southern U.S.A. to South America. Relatively recent incursions of *S. punicea* into South Africa have been reported. Toxicity of *S. marginata*, occurring with *S. punicea* in Argentina, is suspected (Roseveare, 1948), but chicks have survived experimental feedings of its seeds (Williams, 1983).

Poisoning by these species occurs when animals are introduced onto new lands and browse indiscriminately, or when desirable forage is reduced during winter months. Generally, animals do not browse these plants when other forage is available. The toxic principle is in the seeds, which remain on the branches in winter after the leaves have fallen. Sometimes consumption of the plant by one animal will cause others in the herd to eat it also, thereby causing multiple poisonings (Nuessle and Lauter, 1958). These plants often occur in dense stands in low lying, moist soils. Up to 500 kg of seed of *S. drummondii* was easily harvested for research use with a combine from a stand in Texas.

Kingsbury (1964) has reviewed research on the toxicity of American species of Sesbania. Experimental feedings have verified toxicity in chicks, fowl, sheep, cattle, and cats. Poisoning has been observed under natural conditions in goats, hogs, and pigeons. Neussle and Lauter (1958) reported that 25 cattle in one herd were poisoned by S. vesicaria, and that 0.45 kg of its seed killed a 300 kg steer. Experimental feedings have found toxicity in doses ranging from 0.15 to 2% of body weight in cattle. Hens may die from eating as few as nine S. punicea seeds. In sheep, S. drummondii seed was lethal at 0.1% of body weight. Boughton and Hardy (1939) reported that serious poisoning in sheep resulted from feeding S. vesicaria seed at 0.015% body weight, and when fed at 0.06%, death occurred within 12-24 hours. Duncan et al. (1955) fed mice and chicks with a variety of legumes found in southeastern U.S.A.. They found seeds of S. punicea and S. vesicaria to be quite toxic, but leaflets of the latter were not toxic, nor were leaflets or seeds of S. exaltata. Flory and Hebert (1984) studied the lethal effects of S. drummondii seeds fed to chickens; they associated toxicity with kidney damage but did not identify a specific toxin or a mechanism of action for toxicity. Toxicity is found in seeds of Sesbania species in the subgenera Daubentonia and Glottidium, but toxicity has not been reported in species of the subgenera Sesbania which contains the majority of the species in the genus, Agati, or Pterosesbania which contains S. tetraptera and S. rogersii. Seeds of the following species were found non-toxic when crushed, encapsulated, and fed to 1-week-old chicks at 1% of body weight each day for 3 days: macrantha, cannabina, speciosa, bispinosa, sesban, arabica, exasperata, marginata, pachycarpa, sericea, and tetraptera (Williams, 1983).

Sesbanias are known to contain saponins. These triterpenoid compounds are common in the Papillionoideae and particularly in the tribe Phaseoleae (e.g. _Medicago_, _Glycine_, _Phaseolus_, etc.). Saponins may occur in different organs of the same plant and can have allelopathic effects (Langenheim, 1981). Saponins are steroids with sugars attached; when the sugars are removed by hydrolysis, the remaining aglucon moiety of the molocule is a sapogenin. Presence of saponins can be verified by their hemolytic effect on human red blood cells through an interaction with cholesterol in the erythrocyte membrane (Chubb, 1983). Kumar et al. (1982) found that in low concentrations aqueous extracts of leaves of _S. grandiflora_ caused this type of membrane damage, as indicated by liberation of sterols and phospholipids into the experimental supernatant. The presence of saponins is also characterized by a bitter taste and the production of soap-like foam when mixed with water.

The biological activity of saponins is primarily on cellular and membranal components (Chubb, 1983). When extracted, they make superior detergents, and in some countries plants rich in saponins are sold as soap substitutes (Vickery, 1979). Saponins are toxic to cold-blooded animals, and Vickery lists one sesbania, _S. pubescens_ (probably = _S. sericea_), among some of the many plant species used as fish poisons in Africa. Portions of the plants that have high content of saponins are crushed and thrown into a pool or behind a temporary dam slowing a stream, and the fish--usually stunned rather than killed outright--are gathered as they float to the surface. Saponins are widespread in plants but concentrations vary widely: in testing leaf protein concentrates (LPC) as a protein source for grass carp (Ctenopharyngodon idellus), Lu et al. (1977) in Taiwan found that S. sesban ("tienching") LPC caused serious mortality in carp but LPC from Chinese milk vetch (Astragalus sinicus) was not toxic.

Saponins are not especially harmful to warm blooded animals unless injected directly into the bloodstream. In ruminants, they are degraded by the rumen bacteria and depression of growth is not observed. In some monogastric animals, problems may occur if saponin-containing materials comprise a large part of the ration. Alfalfa (Medicago sativa), for example, fed as 20% leaf meal in a poultry ration (equivalent to 0.3% saponin), can cause growth depression, but the same level in a swine ration does not retard growth (Chubb, 1983). Other work reviewed by Chubb found only transient depression of egg production in laying hens fed 0.4-0.5% saponin, while other research suggests that dietary cholesterol can reduce the growth depressing effects of saponins in chick rations.

Investigations on saponin content of sesbania are rather limited. Varshney and Shamsuddin (1964) hydrolysed extracted saponin from S. speciosa with sulfuric acid and found oleanolic acid and two neutral products, one identified as beta-sitostanol (stigmastanol). Oleanolic acid has also been identified in seeds of S. bispinosa (Varshney and Khan, 1962) and leaves of S. grandiflora (Tiwari and Bajpai, cited in Varshney and Shamsuddin, 1964). Oleic, linoleic, and linolenic acids have been found in seeds of S. sesban (Farooq et al., 1954).

The presence of canavanine has been verified in seeds of S. pachycarpa and a variety of S. sesban in West Africa (Chantegrel and Busson, 1964); the amino acid profile reported for these seeds was noted to be particularly deficient in lysine. Canavanine is a basic amino acid resembling argenine, and when it is used as a substrate for enzymes acting on argenine, it is a growth inhibitor. Among legumes, canavanine is apparently confined to the Papilionoideae, where it has been found in 35% of 150 genera and 60% of 540 species examined (Turner and Harborne, 1967). They reported that seeds of eight species of Sesbania were found positive for canavanine, but the particular species names, canavanine levels, and references for the information were not given.

Specific antinutritional effects have been associated with feeding of certain sesbania seeds. Subramanian et al. (1952) fed husked S. grandiflora seed (seed coat and "inner membrane" removed) to rats and observed growth depression. Autoclaving the husked seed did not alleviate the growth depression. Although the seed portion fed had a high protein content of 69.9%, its inclusion at 10% of the dietary protein resulted in weight loss and reduced growth rates compared to casein protein or protein in _dal_ (hulled splits) from _Cajanus cajan_. The authors believed that the poor growth was due to deficiencies in lysine and sulfur-containing amino acids.

Growth was also suppressed in chicks fed seed of _S. bispinosa_. At first, it was speculated that growth depression in chicks was caused by the high gum content of the seed (Katoch et al., 1970). Subsequently, in chick-starter rations, two types of _S. bispinosa_ seed meals, with or without partial removal of gum, were substituted for groundnut cake at 0 to 28% crude protein replacement. Controls (zero replacement) grew best, while increasing levels of substitution significantly decreased growth. Where over half of the sesbania seed gum had been removed from the meal, growth was better, implicating gum content as a cause of growth depression. Chemical analysis did not yield hemaglutinins or goitrogens but did yield tannins (1.37% in mature seeds, 3.4% in immature seeds), and _in vitro_ analysis detected trypsin-inhibitory activity. The trypsin inhibitor was higher in mature seed (26% inhibition per mg protein) than in immature seed (5.2%). Significantly higher pancreas weights in chicks fed sesbania meal were attributed to the trypsin inhibitor (Katoch and Chopra, 1974a).

Further study with autoclaved seed meals indicated that although the trypsin inhibitor was thereby denatured and chick growth improved, pancreas weights were still high relative to controls. The authors suspected that an unknown, heat-resistant factor caused the pancreatic hypertrophy (Katoch and Chopra, 1974b). Growth was greater in chicks fed autoclaved meal (at 28% crude protein replacement in the ration), with or without partial removal of endosperm, compared to those fed raw meals. Control birds that received no sesbania meal still gained more weight. Feed utilization efficiency of autoclaved meal with endosperm partly removed was equivalent to that for the control, but consumption of control ration was higher. The authors noted that autoclaving removed some of the odor of the raw seed meals, so it is possible that palatability may have been a factor in lowering growth rates when S. bispinosa seed meals were included, autoclaved or not.

Sesbania foliage is generally considered innocuous, but some negative results have been reported. A toxicity screening was conducted with the foliage of S. grandiflora, the closely related S. formosa, and 2 varieties of S. sesban. Six, 1-week-old chicks were fed dried, encapsulated leaves at 1% of body weight each day for 3 days. All chicks died before the 5th day when fed S. grandiflora and two varieties of S. sesban. No toxic signs were observed in any chicks fed S. formosa (Williams, 1983). In a feeding study in India, S. grandiflora leaf meal was included in chick-starter rations, and feed consumption and chick growth was decreased at the first increment (5% of the ration). Mortality increased compared to controls (13-15% v.s. 3%), but not with increasing proportions of leaf meal (Prasad et al., 1970). Hutagalung (1981) mentioned S. grandiflora as a browse tree with considerable potential as a feed source in the tropics, but in a table of dietary inclusion rates, recommendations for poultry and pigs were low: 2-5%. The same author also made a vague reference to toxic effects on livestock of the "purplish flower variety of Sesbania."

These few reports indicate that caution is appropriate in feeding sesbania foliage to monogastrics. No negative reports were found to suggest that sesbanias could not be used as a source of fodder for ruminants. Feeding studies with sheep and goats discussed in our section on nutritive value of sesbania materials do not suggest any deleterious effects. In Indonesia, S. grandiflora is said to be sometimes fed as the sole ration to milking goats. In India, S. sesban offered for sale in markets was reported to be bought principally for feeding sheep and goats (Anon., 1924). In non-experimental feedings in Hawaii, pregnant goats fed S. sesban and S. grandiflora as a major element of their diet had normal kidding and lactation. The growing of sesbanias as sources of feed for ruminant livestock is, therefore, to be encouraged.

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7. SESBANIA SPECIES AS PULP FIBER RESOURCES.

Sesbania bast fiber for cordage.

Harvesting of various *Sesbania* species for their epidermal stem fibers is an ancient practice. The common sesbania of the Americas, *S. exaltata*, has been used as a fiber source for nets and fishing line by the Yuma Indians of Arizona (Parker, 1972), and by other indians throughout its range. The common epithet for the species, Hemp sesbania, or Colorado River hemp (Robbins et al., 1971), reflects this utility. South Asia's common, annual counterparts to *S. exaltata*, namely *S. bispinosa* and its close relatives, have been similarly used, especially in the Bengal-Bangladesh region (Sircar, 1948). There also, the material has been found especially appropriate for fishnets because it resists decay in seawater (Mazumdar et al., 1973). This tolerance of wetting accounts for numerous maritime applications, such as sail lashings, for the coarse but very strong and durable cord and rope made with bast from *S. bispinosa*. In Central India, *S. bispinosa* fiber is known as Dundee fiber and has been regarded as a substitute for *Crotalaria juncea*; it is said to be stronger and more durable than jute fiber (Townsend, 1973).

Recovery of stem fibers is done by submerging bundles of stems in water for an appropriate period of time. Hussain and Ahmad (1965) describe immersion for 25 days, then drying and hand-peeling of the bast, resulting in a yield of about 9% of the total stem dry weight. Shorter soaking times such as 2 weeks as mentioned by Uppal (1955) are probably adequate. Medvedev (1936) reports fiber recovery by a process referred to as heat maceration. Stem samples were macerated at an air temperature of 35-37C for from four to nine days, depending on plant growth stage; "overripe stalks," harvested during seed ripening stage, required the longer maceration period. Specific details of the process were not given. Fiber yield was 6-7% of the air-dry weight of stalks. In India, Maiti (1980) reported a fiber yield of 9% of S. bispinosa whole plant weight. He judged the fibers to be of poor quality compared to jute (Corchorus spp.), Hibiscus spp., and Urena spp.; these others also had much better fiber yields, ranging between 26 and 49% of stems.

The actual extent of use of these plants as fiber resources for string and cordage is unknown. The species are widespread in the tropics and subtropics, but this use of their fibers is a local phenomena more in the realm of ethnobotany than of economics, uncataloged except for instances such as in India where some small commercial importance has developed. Because of expanded availability of synthetic fibers, the potential for use of sesbania fiber for cordage is probably rather small.

Sesbania for pulp fiber.

The use of stems for pulp manufacture has better probability for future development and increases the number of potentially useful species to include other partly woody annuals as well as perennials such as S. sesban and S. grandiflora. The fast-growing annual S. bispinosa, however, has been the species of principal interest as a commercial pulp fiber crop. Some properties of sesbanias relevant to pulping qualities are given in Table 1.

Table 1. Some properties of stems of *Sesbania* species.

Characteristic, unit	Value	Species	Fraction	Reference
bulk density, kg/m^3	300	bispinosa	stem	FAO, 1979
	240-320	"	"	Pai et al.
	616 (38.5 lb/ft^3)	cannabina	"	Razzaque et al.
	356	grandiflora	"	Logan et al.
	512 (32 lb/ft^3)	"	"	Bhat et al.
	420	"	"	NAS, 1980
	432	sesban	"	NAS, 1983
fiber length, mm	2.0	bispinosa	bark	Mazumdar
	2-4	"	"	Sircar
	1.36-2.53	various spp	"	Wood & Gartside
	0.55-0.84	"	core	"
	0.96	bispinosa	pulp	NAS, 1976
	0.6-0.7	"	"	Pai et al.
	0.793	"		Razzaque et al.
	1.07	grandiflora	pulp	Bhat et al.
	1.1	"	"	NAS, 1979
	1.14	"	"	Logan et al.
lignin, %	20-22	bispinosa		FAO, 1979
	21.1	"		Pai et al.
	16.3	"		Mazumdar
	16	various spp	core	Wood & Gartside
	21	grandiflora		Bhat et al.
cellulose, %	45-46	bispinosa		FAO, 1979
holocellulose, %	77.2	"		Pai et al.
	85.24	"		Mazumdar

Values for bulk density in Table 1 are generally higher than those found in field experiments with annual *Sesbania* species in Hawaii (Evans and Rotar, in preparation). Bulk density of accessions grown at a population of 125,000 stems/ha (20x40 cm spacing) was measured at maturity with sections sampled at the gravitational midpoint of stems trimmed of branches. Among 32 accessions sampled, average bulk density was 215 kg (bone dry)/m^3, with a range of sample means from 158 to 284.

The scope of research interest.

Technical papers on pulping characteristics of *S. bispinosa* and other sesbanias have been published by workers at the Indian Council of Agricultural Research's Jute Technical Research Lab, Calcutta (Mazumdar et al., 1973); the Parkhe Research Institute, Khopoli, India (Pai et al., 1980); Australia's Council of Scientific and Industrial Research (CSIRO) (Wood and Gartside, 1981); and the Pulp and Paper Branch of the Forest Industries Division, Forestry Department, Food and Agriculture Organization of the United Nations (FAO) (Markila, 1979). Other fiber testing for pulp manufacture has been done in northern Pakistan by L. Markila in 1961, in Scandanavia in 1963 (FAO, 1979), and in Detskoye, USSR (Medvedev, 1936).

Trial plantings either to select suitable sesbanias for pulpwood or to manage *S. bispinosa* as a plantation crop have been conducted by the Ayub Agricultural Research Institute, Lyallpur, Pakistan (Hussain and Ahmad, 1965); U.S. Department of Agriculture (Jones and Wolff, 1960); the USSR's All-Union Scientific Research Institute of Plant Growing (Medvedev, 1936); Sandwell Paperconsult in southern Italy in 1963-1964 (unpublished); CSIRO (Wood, 1976); UNFAO in cooperation with the Italian Ente Nazionale per la Cellulosa e per la Carta at sites in Casalotti, Rome and Catania, Sicily in 1979; and The Parkhe Research Institute at Khopoli, at Pune, Maharashtra, and at Fort Songadh, Gujarat, India. Recent observation and selection plantings have been conducted by CSIRO at Lawes, Queensland (I.M. Wood, personal communication), and by the Department of Agronomy and Soil Science, University of Hawaii, at Waimanalo, Oahu, Hawaii (Evans and Rotar, in preparation).

Recorded utilization of sesbanias as pulpwood.

In a review on the multiple potentials of S. bispinosa, Hussain and Ahmad (1965) stated that a paper mill in (West) Pakistan was using it after its main raw material (Eulaliopsis binata) ran short. S. speciosa had been imported and was under consideration as a replacement for S. bispinosa, which was said to be "too fibrous and woody," perhaps because the monosulfite pulping process used by the mill to pulp reeds was too mild for woody material. Another reference to the commercial use of S. bispinosa as a pulp source was in a report to the TAPPI Non-wood Fiber Conference, where Pai et al. referred to commercial scale plantations for plant scale trials at Central Pulp Mills, Fort Songadh, Gujarat, India. More recently, Dutt et al. (1983) mentioned that S. sesban was being sown on a plantation scale in India, and that the West Coast Paper Mills at Dandeli, Karnataka, and the Andra Pradesh Paper Mill at Rajahmundry have reported yields of 50-55 tons green wood/ha/year under irrigated conditions.

In Indonesia, S. grandiflora (locally called "turi") has been used as a commercial pulpwood source in East Java. According to Dr Roehyati Joedodibroto of the Institute for Research and Development of Cellulose Industries, Bandung, Indonesia, (personal communication, 1984), a mill at Banyuwangi has for some time used turi in mixture with bamboo, sources of which are becoming increasingly depleted. The turi is obtained from farmers throughout East Java, where it is grown on rice field dikes and bunds and the foliage is fed to livestock or used as green leaf manure; trial plantations of this species near the mill site were said not to have been successful, possibly because of inadequate rainfall. An economic analysis of the establishment of these plantations was done (Sriyanto, 1978), but was not available for review.

Estimated yields of Sesbania species for pulp fiber.

One of the first records of stem yields of S. bispinosa was a measurement taken in a farmer's field at harvest time in November, 1961, in northern Pakistan: a yield of 15 bone dry Mg/ha was estimated (Markila, 1979). In trials in southern Italy using seed imported from Pakistan, yields were 14 bone dry Mg/ha. Most other published yield information on sesbanias concerned fresh yield of succulent green manure or fodder materials.

In Hawaii, over 30 accessions of annual Sesbania species were tested for productivity during a 14-week growth period in the summer of 1983 (Evans and Rotar, in preparation). Twenty-three of the entries were categorized as high yielding varieties (HYV's), with total dry matter yields >10 Mg/ha and nitrogen accumulations >150 kg/ha; these had a mean of about 13 Mg/ha dry matter and a maximum of 17 Mg/ha (bone dry weights are approximately 10% less). There was an average of 53% (range 24-84%) of their dry matter in the stem fraction at harvest, with a resulting average of 9.25 Mg/ha dry matter in the stem fractions. Most of the accessions in this group were those received as S. bispinosa or its close relatives S. cannabina and S. sericea; other species included S. emerus and S. exasperata from South America, S. simpliciuscula from Australia, and S. rostrata from Africa.

S. grandiflora's yield characteristics have been studied recently because this perennial has potential as a source of fuelwood as well as of pulpwood. Bhat et al. (1971) estimated that if planted at 12,000 plants/ha (90x90 cm spacing) and with 75% survival, in three years the trees will average 8 m height, 8-10 cm diameter at breast height, and yield 125 Mg/ha air dry wood. In Indonesia, wood yields of 20-25 m^3/ha/year are reportedly obtained (NAS, 1980). This species has been studied among other nitrogen-fixing trees in growth trials in Hawaii (MacDicken, 1983). In these experiments at 4 sites, best performance was obtained with Leucaena spp., but S. grandiflora exhibited rapid early growth and equalled at least one of the Leucaena spp. in wood volume at every site at 1 year from transplanting of seedlings. At that time average height of S. grandiflora was 3.3 m, mean basal area was 24.5 cm^2, and mean estimated wood volume was 24.6 m^3/ha (values were 24.3, 56.8, 19.6 and 5.5 m^3/ha) for the 4 sites. Further data on this tree's performance will be forthcoming because of increasing worldwide interest in fast-growing trees, including the expansion of these species trials into an international network of sites by the

Nitrogen Fixing Tree Association (P.O. Box 680, Waimanalo, Hawaii 96795 USA).

Expected yields of S. sesban are not well known. Members of this species complex are generally very fast growing, making it an appropriate candidate for further research. One limitation is that, like S. grandiflora, its wood is rather light and it therefore may not be appropriate for other than short-haul transport. One source mentions yields of 30 "tons per acre" obtained in 1 year in India (NAS, 1983). Dutt et al. (1983) reported that yields of 50-55 Mg/ha/year green wood have been obtained under irrigation in trials by Indian pulpmills. In plantings in Jammu (subtropical, elevation 300 m, 1000 mm rainfall), Dutt obtained 17.8 Mg/ha dry wood in 1 year,.and a 3 year old planting was estimated to contain 77 Mg/ha dry wood. From their growth data it appears that early growth is quite rapid: mean plant height at 15 months (6.7 m) and mean diameter at breast height (7.1 cm) recorded at 3 sites were 89% and 84%, respectively, of values obtained at 24 months.

Technical literature on pulping S. bispinosa.

Laboratory experiments on pulping and papermaking with S. cannabina were reported by M.A. Razzaque and A.B. Siddique of the Forest Research Institute, Chittagong (1971). (The near-synonomy of this species with S. bispinosa, coupled with general nomenclatural confusion on the part of most non-botanists, would tend to support the assumption that pulping chracteristics of their test plant and the "S. aculeata" or S. bispinosa of other authors are similar if not identical.) They prepared pulps by kraft, neutral sulfite semichemical (NSSC), and hot soda processes; cold soda process was found ineffective because the low-density material floated and resisted chemical impregnation. In general, as chemical consumption increased, yield decreased, but tear factor also decreased and burst factor, breaking length, and folding endurance increased. Longer pulp beating times, inversely related to freeness values, produced like effects on strength properties. The kraft pulp at 250 ml Canadian Standard freeness compared well with tropical hardwood pulps and with birch in regard to chemical use, yield, and strength. The kraft pulp was considered adequate for wrapping, printing, and writing grade papers, and the NSSC pulps produced superior grade glassine papers.

Some general technical considerations of the pulping characteristics of S. bispinosa stems were reported in 1979 by L. Markila. That author's tests conducted in 1961 in Pakistan also revealed a material having low density, and delignification and pulping chemical consumption similar to hardwoods. The pulps also had good bleachability. More extensive, unpublished testing by a Scandinavian research institute confirmed Markila's findings and again indicated similarity between S. bispinosa pulp and birch pulps (Markila, 1979).

An extensive laboratory evaluation of S. bispinosa pulp was reported in 1980 by P. A. Pai et al., presenting data from research by the Parkhe Research Institute on pulping, bleaching, beating, sheet making and sheet testing, and on black liquor characteristics. They found that the wood had low chemical requirements for pulping and bleaching, equal to or slightly less than those for bamboo and Indian tropical hardwoods, and the bleached pulp had high brightness stability. Pulp yields were also comparable to bamboo and superior to tropical hardwoods. Because of the lightness of the wood, it was easily chipped and was judged to be more adaptable to continuous than to batch digestion processes because of low digester yields per batch loading. Fast beating times of pulps preserved tear and opacity and in addition conserved beating energy. Tear index was said to be improved by blending with longer fibered pulps, and this appeared necessary in order to run the material on high speed paper machines. Blending of the black liquor with liquors from bamboo or softwood was also thought desirable to improve evaporation and chemical recovery furnace burning characteristics.

According to unpublished information, a mill-scale trial run was carried out in 1980 at the Parkhe Organization's Central Pulp Mills in Fort Songadh. The trial run was based on materials from the trial plantations mentioned above. In this trial unbarked S. bispinosa was the sole fiber supply and printing and writing papers were produced. The results were said to be encouraging and to confirm earlier laboratory test results. The strength factors of the papers produced were comparable to those of the bamboo-based papers normally produced in the mill. Even the tear strength was close to that of bamboo papers. This could be explained by the fact that S. bispinosa plants were pulped with all branches, in which long-fibered bast fiber content is proportionally higher than in the stems used in the laboratory tests. Black liquor characteristics could not be checked because the liquor was mixed with bamboo black liquor from preceeding mill operations.

Technical literature on pulping S. grandiflora and other sesbanias.

Extensive laboratory data on pulping of Sesbania grandiflora has been published by Bhat et al. (1971); the work was done in India, but their institutional affilliation was not given. They reported on the preparation and bleaching of conventional kraft, NSSC, and cold caustic pulps. Because of high initial brightness of the wood, the production of high pulp yield with moderate strength properties and medium brightness was persued, with favorable results from the NSSC and cold caustic pulping methods. Optimal cold caustic pulping involved presteaming at 140 C for 15 minutes and soaking in 7% caustic at 45-50 C for 2 hours, resulting in 80% pulp yield. Strength properties of both laboratory and pulping plant-produced S. grandiflora cold caustic pulp mixed with bamboo chemical pulp in the range from 0-100% were reported; mixtures with 40% S. grandiflora pulp were suitable for inexpensive grades of printing, writing, and magazine papers.

Pulping research on S. grandiflora in Indonesia has found that a medium strength, bleachable pulp can be obtained at yield levels of 45% by cooking with 15% active alkali at 22% sulfidity

(R. Joedodibroto, personal communication).

S. grandiflora has also been considered as a pulpwood source for northern Australia (Logan et al., 1977). Material tested was 4.5 years old, required debarking, and gave "moderately low" yields of sulfate pulp, suitable for "a limited range of...products" including bleached paper grades. Papermaking quality data given included tear indices and breaking lengths for materials from NSSC and bleached and unbleached sulfate pulps, and breaking lengths and crush resistances of NSSC materials at varying freeness values. Pulp obtained by NSSC process was found to be suitable for corrugating medium (at Kappa numbers of 120-130), although "severe" cooking conditions were required for adequate delignification. Vessel picking and surface roughness tests on handsheets indicated possible use in production of printing papers. *S. grandiflora* was found to be compatible with kenaf for co-pulping by the sulfate process; the resulting pulp's drainage rate improved in proportion to the admixture of sesbania pulp, without any decrease in strength properties.

A number of other *Sesbania* species have recently been considered for pulpwood production by CSIRO, Australia. Brief data from research at the Division of Chemical Technology in Melbourne has been reported for seven species including *S. cannabina*, *S. sesban*, *S. tetraptera*, *S. simpliciuscula*, *S. pachycarpa*, and *S. marginata*. Stem core and bark fractions were analysed separately, but pulping of whole, unseparated stems was recommended. Pulps were prepared by the soda process; drainage times were similar to commercial hardwood pulps but pulp yields were termed low. The *S. sesban* and *S. cannabina* accessions tested were designated as having potential as pulpwood crops based on their agronomic characteristics and their physical and chemical pulping properties (Wood and Gartside, 1981).

The world need for new pulp fiber resources.

The demand for paper products increases at rates far faster than present natural or managed resources can supply, and chipping of tropical hardwoods for pulps joins with fuelwood needs and timber exploitation as a contributor to the present mass-scale deforestation. Non-wood fiber pulps, including *S. bispinosa*, represent an alternative which although small (7% of global use in 1977) is particularly important in developing countries which along with the Peoples Republic of China, a major non-wood fiber user, accounted for 83% of the world's use of these materials in 1977 (FAO, 1979). Economic growth in developiong nations resulting in higher literacy, increased consumerism, and other indices of the physical quality of life will inexorably increase per capita paper consumption.

Large scale multinational pulp production industries require vast forest resources, and their economies of scale dictate predictable resource availability several decades into the future. Many of these are now based on coniferous plantation forests. Few developing country pulp industries supplying domestic markets operate at such a level. Plant capacities are low. They must work with local resources, often various and subject to seasonal availability. Traditional fiber sources often limit productivity and type of output of these operations: competition for crop residues for feed or fuels used domestically or industrially (e.g. sugarcane bagasse) limits the use of these types of materials; residue from long fiber crops such as cotton and flax and other sources such as abaca (Manila hemp) or sisal produce expensive, high grade, special purpose papers; jute is suitable only for low grade paper and board (FAO, 1979). Bamboo, the major raw pulp material of India, is slow to establish, production is interrupted by gregarious flowering and subsequent senescence of entire stands, and yields on an area basis are low (0.5 to 4 t/ha/yr), with a 3-4 year cutting cycle, so that vast areas are needed (Pai et al., 1980).

Fast growing annual tropical plants which have suitable pulping qualities and can be managed on a plantation scale are attractive alternatives or supplements to such traditional fiber sources. Kenaf (*Hibiscus cannabinus*) is such a crop and has recently been seriously considered as a pulp fiber crop for Australia's tropical region (Wood et al., 1983). Its bark (20-25% of the stem) has coarse long fibers which produce excellent pulp, but the short (0.5-0.6mm) fibers contributed by the core dilute overall pulp quality; nevertheless, yields of two crops per year are possible, and hopes for its development as a basis for pulping industries remain (FAO, 1979). Kenaf has also been investigated in the USA by USDA's Northern Regional Research Laboratory in Peoria, Illinois; during recent years these investigations have concentrated on kenaf's use for newsprint manufacture.

Interest in Australia in Sesbania species developed partly in cognizance of the nitrogen fertilizer input required for kenaf, amounting to about 35% of the cost of its production (Wood, 1976). In addition to the advantage of nitrogen fixation, sesbanias may be more suitable for growing on problem soils which are salt affected or occassionally flooded. The woody stems of many sesbanias are easier to handle and to store than those of kenaf. Perennials like S. sesban may be ratooned, or coppiced; these and even some annuals may in certain instances be cut once for fodder or green manure, promoting branching in the regrowth to be harvested for pulping. Seed may also be harvested for extraction of gums. Given the diversity among subspecies and varieties of S. sesban observed in accession plantings in Hawaii, there seems to be ample opportunity for selection and breeding of this and other Sesbania species for pulpwood production on a wide range of possible sites.

Summary.

The goal of pulp enterprises is to establish a secure raw material supply which will provide good quality fiber at the lowest possible cost. In developing countries, raw material requirements of many mills are small, and fast growing annual or perennial crops can be pulpwood sources offering considerable flexibility. A number of woody Sesbania species have been found to be suitable pulp sources in terms of technical pulping and milling considerations. Wide scale growth of S. bispinosa as a green manure crop in Southeast Asia indicates that the crop is readily managed by farmers in a variety of agricultural situations. Factors such as the rapid growth and multiple uses of these plants, the benefit to the soil accrued by growing legumes, and the reduced need for fertilizer inputs compared to non-legumes enhance their desirability from the farmers' point of view, which in turn would contribute to assuring a more secure fiber supply to the mill.

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8. SESBANIA SPECIES AS SOURCES OF GUMS.

Many sesbanias contain gums which may be of potential value for industrial purposes. Natural gums, or mucilages, are complex polysaccharides which have a wide range of uses. Their varying physical properties are attributed to differences in the degree of branching of and polymerization of the sugars. In food processing, gums lend stability and smoothness of texture to products by emulsifying, thickening, stabilizing, and binding the ingredients. Examples of food products containing gums are ice cream, candy, soft drinks, beer, pastries, and heat-and-serve convenience foods. Gums are also used in manufacture of paper, textiles, and paints, in well-drilling and in mineral assay.

Bark gums.

Some sesbanias exude gum from their bark when cut or damaged. This feature is particularly notable in *S. grandiflora* and the closely related *S. formosa*; it is also present in *S. sesban* and other species. These gums upon exudation are red or white tinged with red; they become dark red-violet after exposure to air and hardening. Burkill (1935) cited West and Brown as stating that *S. grandiflora* bark gum is similar to gum arabic. De Sornay (1916) mentioned that the gum dissolves in water, floats in alcohol, and that the pigmentation could be separated into two principles: a red "agathin" and a yellow "xanthoagathin." Burkill mentioned that these gums were not known to be collected in Malaya. A U.S. National Academy of Sciences report (NAS, 1979) stated that sesbania bark gums have been used as substitutes for gum arabic, and suggested that with increasing scarcity of this substance as derived from *Acacia senegal*, sesbania bark gums should be investigated.

Seed gums.

The more likely source of gum from sesbanias is the gum contained in their seeds. Export of seeds for gum extraction has become a foreign exchange source in Pakistan and India, based on the international demand for gums from seeds of guar, *Cyamopsis tetragonoloba*, a plant adapted to semi-arid tropical and temperate zones (Whistler and Hymowitz, 1979). Pakistan's first processing plant to produce guar endosperm splits, thereby reducing shipping volume, was established in 1955; at about that time, the Ayub Agricultural Research Institute in Pakistan began to consider alternative gum sources, including the sesbanias *S. sesban* and especially *S. bispinosa* (Hussain and Ahmad, 1955; Hussain and Khan, 1962a and b)). More recently, India's National Botanical Research Institute at Lucknow has nominated *S. bispinosa* as a gum source worthy of consideration (Chandra and Farooqi, 1979), and the U.S. National Academy of Science has included that species among a number of legumes with potential as gum producers (NAS, 1979). Very little published information is available on sesbania seed gums, and despite a diversity of species in the genus, few species other than those mentioned above have been considered.

Generally in legume seeds, endosperm tissue is absorbed during seed maturation into the developing cotyledons and only a thin remnant remains in the mature seed. In some legume seeds such as those of guar and S. bispinosa, the endosperm is not so fully absorbed, and constitutes a sizeable portion of the seed. The endosperm portion of S. bispinosa seed is stated to be in the range of 30-42%, about 75% of which is galactomannan (Chandra and Farooqi, 1979). This range agrees with data reported by Hussain and Khan (1962b) who found 33-36% gum in S. bispinisa seed samples from six regions in Pakistan; they found slightly less gum (31-32%) in S. sesban. They found that the endosperm was about 90% extractable N-free carbohydrate, and yielded 85-88% galactose and mannose in a ratio of about 1:4.7.

Anderson (1949) estimated endosperm percentages of a large group of North American legume seeds by cutting through mature seeds and recording approximate proportions of endosperm. He obtained the following values for sesbanias: 20% for S. cannabina, S. exaltata, and S. macrocarpa (the latter two being synonyms); 10% for Daubentonia drummondii; 15% for Daubentonia punicea; 2% for Glottidium vesicarium. Extraction of soluable mucilage from S. macrocarpa seed by boiling whole seeds resulted in a yield of 18% of the total seed. In his study, guar had 50% endosperm by visual estimation and 42% endosperm by mechanical separation. Tookey and Jones (1965) have also reported on extracted gum proportions in American sesbanias. They found about 10% N-free gum (i.e., protein removed) in S. drummondii, S. exaltata, and S. macrocarpa, 13.8% in S. sonorae (=S. exaltata), and 8.7% (crude basis) gum in S. vesicaria. Guar seeds had 22-25% N-free gum.

S. cannabina seeds have been analysed for gums along with other legume seed gum sources found in China. They were found to contain 33.5% endosperm (Li et al., 1980), and the gum's chemical structure was investigated (Anon., 1978).

S. grandiflora seed gums have been examined and their chemical characteristics elucidated in detail by workers at the Central Food Technological Research Institute at Mysore, India (Rao and Rao, 1965), and later at the Ahmedabad Textile Industry Research Association (Srivastava et al., 1968). According to these investigators, gums were associated with the tegmen, or inner seed coat, and constituted about 20% of the weight of mature seeds. Water soluble polysaccharide in the gum was over 90% galactomannan with a D-galactose:D-mannose ratio of 1:2. Li et al. (1980) found the same ratio in *S. cannabina*. Rao et al. (1980) have also studied seed gums in *S. speciosa*, which contained galactose and mannose in a ratio of 1:2.2. With both species examined, hydrolysis of the fully methylated polysaccharide yielded 2,3,4,6-tetra-O-methyl-D-galactose, 2,3,6-tri-O-methyl-D-mannose and 2,3-di-O-methyl-D-mannose, in equimolar proportions for *S. grandiflora* and in 1:1.1:1 ratio for *S. speciosa*.

In a technical report on gum physical properties originating from Lucknow (Kapoor and Farooqi, 1979), seed gums extracted from *S. bispinosa* endosperm were found to be readily soluble and easily dispersed in water; hydration was complete in 1 hour with stirring. Solution concentrations of 1% had viscosities of 400 centipoises (cP), rated low, but concentrations of 2% gum produced solutions with viscosities in excess of 3000 cP. The non-ionic gum showed stable viscosities below pH 9.0, but above that level gelling began and viscosity rose sharply. Fluxes in viscosity resulting from shifts of solution temperature were stated to be indicative of unusual properties. The gum was judged to be similar to other commercial gums such as guar and carob (Ceratonia siliqua).

Huang et al. (1980) in the Peoples Republic of China have investigated the physical chemistry of gum from seeds of S. cannabina. Isolated and purified gums were found homogenous after ultra-centrifugation. Data showing trends of variation with gum concentrations of values for sedimentation coefficient and reduced viscosity of gum solutions obtained from both alcoholic purification and copper alcoholic purification were given. The former purification had molecular weight 391,000, while the latter had mw 206,000 and correspondingly lower values for intrinsic viscosity and sedimentation coefficient.

Seed yields.

Seed yields of S. bispinosa have been reported at 1.5 MT/ha in Pakistan (Hussain and Khan, 1962a). Yields in this range and greater are probably obtained by taking one or more top cuts during the vegetative growth period to stimulate branching: floral racemes arise from branch axils. In a farm-scale economic analysis for India conditions, Chandra and Farooqi (1979) set 1 MT/ha as a minimum yield. This appeared to be based on earlier work at Lucknow, where on saline-alkali lands of soil pH 8.9, S.

bispinosa sown at 75x45cm produced an average of 1 MT/ha seed over two seasons of experiments with differing sowing dates and N and P fertilizer levels (Misra and Singh, 1976). The value of stems as fuelwood accounted for one-third of the gross profit. Their analysis did not include cost of an early cutting to stimulate seed production or the value of the fodder or green leaf manure thus obtained; such a practice might result in reduced yield of the fuelwood component, but if it increased the yield of the less bulky and more easily handled seed component, it would be worth consideration. At Varanasi in India, on a sandy loam soil, R.G. Singh (1971) obtained an average seed yield of 2 Mg/ha (and a maximum of 2.5 Mg/ha) when phosphorus was applied. Stem yield averaged about 15 Mg/ha, and the average yield ratio of harvested stem to seed was 6.5.

These seed yields for *S. bispinosa* are similar to yields found in seed increase plantings in Hawaii, where at low plant populations and without management to enhance seed production, yields equivalent to approximately 1.5 MT/ha were obtained for accessions of *S. cannabina* from Australia, *S. macrantha* from Africa, and *S. sesban* from Egypt (Evans, unpublished data). There is obvious scope for consideration of other *Sesbania* species or for selection or breeding of varieties having higher seed yields, lack of pod shattering upon drying (a problem with *S. bispinosa*), higher galactomannan content, lower tannin content, resistance to pod pest infestation, and response (or lack of response) to cutting management designed to increase seeding. Seed yield under varying planting dates, where possible, should be considered, since many annuals have different growth forms under flowering-inductive and non-inductive daylength conditions. Misra and Singh (1976) found higher yields for sowings in June than earlier (April, May) or later (July) in India, but differences there appeared to be caused by seasonal climatic variations in temperature, rainfall, and winds.

Co-products of *Sesbania* seed gums.

While *S. bispinosa* seed gums can be a marketable product, the adaptability of the plant and the presence of co-products make it yet more attractive. It can be grown on lands affected by soil alkalinity and salinity--an estimated 17 million hectares of these lands are left uncropped in India (Chandra and Farooqi, 1979)--and when sown in such areas will not compete with cropland. The value of stems for fuelwood has already been noted. An additional potential exists for utilization of the seed after removal of the endosperm, in cases where such processing is done locally.

The whole seed consists, in its general parts, of the seed coat (testa, sometimes referred to as "husk"), the endosperm containing the gum, the cotyledons, and the germ (embryo, plumule, and radicle). Sometimes the terms "kernel" or "meal" are used to describe the fraction that is neither seed coat nor endosperm; sometimes the term "seed meal" refers to the entire residue after removal of the endosperm, i.e. the kernel plus the husk. Table 1 summarizes analytical data on *S. bispinosa* seeds and seed fractions. Kapoor et al. (1979) have reported on the fatty acid composition of S. sesban seeds.

Seed meals have been considered in Pakistan as substitutes for peanut meal as an ingredient in culture media for growth of penicillium. While seed byproducts from guar processing were not suitable, S. bispinosa appeared to be usable in the range of 3.5-4% of the media mixture (Hussain and Ahmad, 1955). However, there has been no information on this type of use published subsequently.

S. grandiflora seed proteins were considered among other plant seeds in a study searching for vegetable adhesives for plywood manufacture and related uses (Narayanamurti, 1957). High protein contents were found, and about half of the protein nitrogen was extractable with water, compared to 75% for Crotalaria juncea which was the highest extractability of seeds tested. Some additional analytical data was given but no conclusions were made as to the relative suitability of S. grandiflora seeds as a source of proteins for glue. Markila (1979) has suggested that S. bispinosa seeds may be a source of adhesive gums for the papermaking industry.

There would be more scope for use of Sesbania seed meals in preparation of animal feeds. In mentioning feeding experiments which apparently used whole seeds, Hussain and Khan (1962a) reported that whole ground seeds were unpalatable to cattle, but in mixture with cottonseed meal, wheat bran, and molasses, palatability was maintained with up to 33% ground seed in the feed. Sesbania seeds and seed meals have been considered for poultry feed (Katoch and Chopra, 1974a and b; see section on anti-nutritional factors), and while removal of the gum rendered the meal more acceptable as a ration element, it appears that further information is needed regarding the effect of including these seed meals in animal diets.

Table 1. Analysis of S. bispinosa seed fractions.**

Fraction	Ref.*	% of seed	Protein	Fiber	NFE	Fat	Ash	Ca	P
seed coat	1	20	8	46	44		8.4		
	2	16-20	16	25	4	0.5	4.5		
endosperm	1	33	6	7	90		1.2		
	2	30-42	16	2	73	0.7	0.6		
	3	25							
kernel	1	45	58	4	27		4.6		
	2	42-46	61	8	19	7.0	4.1		
	3	-	51	8	30		3.5	0.20	0.67
whole seed	1	100	27	13-29	50	4.2	3.3-5.4	0.44	0.99
	3	100	32	11	48		4.1	0.15	0.47
seed meal	2	-	43	11	17	6.5	4.2	0.50	0.90

** values are percentages and have been rounded.

* Reference 1 values from Hussain and Khan (1962a); the same % seed fractions were reported by Li et al. (1980) for S. cannabina.

Reference 2 values from Chandra and Farooqi (1979).

Reference 3 values from Katoch and Chopra (1974a); they prepared "dal" by pounding seeds and winnowing to remove husk and about 43% of the endosperm gum.

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9. MEDICINAL USES OF SESBANIA SPECIES.

Traditional medicinal uses of *Sesbania* species, particularly *S. grandiflora* and *S. sesban* and to a lesser extent *S. bispinosa*, are known in Asia, but we have not found evidence of such uses in the Americas. Information published in Watt's Dictionary of the Economic Products of India (1889-1893) has been often repeated and added to in subsequent compilations (e.g. The Wealth of India by India's CSIR (1972), Burkill (1935) for Malaysia, Quisumbing (1951) for the Philippines, Neal (1965) for Hawaii.) For Africa, Watt and Breyer-Brandwyck (1962) have summarized uses which may apply to a number of the sesbanias found there.

S. grandiflora juices and extracts have an astringent quality, contracting body tissues and blood vessels; they are used for reducing fever, promoting fluid discharge and subsequent drying of mucous membranes and other tissues, and as antihistaminics. For systemic disorders (e.g. smallpox and other fevers), decoctions are taken internally. Local applications are said to bring relief to nasal congestion and rhinitis, and headache associated with sinusitis: juice of leaves and flowers "blown up the nostrils...causes a copious discharge of fluid relieving the pain and sense of weight in the frontal sinuses;" juice of flowers applied to the eyes is said to relieve "dimness of vision" (Watt, 1893). The bark also has these astringent, tonic, and febrifuge qualities. In Java it is used for thrush and stomach trouble in infants (Burkill, 1935). Leaves are said to be aperient (laxative). Root juices are used as an expectorant;

poultices of roots and leaves are applied for rheumatism, swellings, bruises, and itching.

<u>S. bispinosa</u> appears to have similar astringent qualities, promoting healing and the discharge of pus. Pastes of the seeds, sometimes mixed with flour, are applied to ringworm, other skin diseases, and wounds (Duke, 1981; Hooper and Field, 1937). The latter authors report a superstition in India that mere sight of the seeds relieves pain of scorpion stings.

Uses of <u>S. sesban</u> are similar to the above but with even wider applications in terms of specific ailments, and some unique qualities not mentioned for the others. The quality of astringence is apparently quite powerful in sesban. Fresh root and poultices of leaves have been used for scorpion stings, boils, and abcesses. Rheumatic swelling and hydrocele (a collection of watery fluid in a cavity of the body, especially in the scrotum or along the spermatic cord) are said to be resolved by application of poultices of leaves; diarrhea and excessive menstrual flow are said to be relieved by the seeds; doses of up to 2 ounces of leaf juice may be given as an antihelminthic against intestinal tapeworms and roundworms (Watt, 1893).

Even more imaginative uses of sesban are reported for the Haya of Africa, who use it ("mubimba") for sore throat, gonorrhea, syphilis, yaws, fits in children, and jaundice during pregnancy. In West Africa it is used against fever and guinea-worm (Watt and Breyer-Brandwyk, 1962). Decoctions of the leaves are reportedly used by the Hausa people as a drench for cattle to repel the tsetse fly (Gohl, 1975; CSIR, 1972). Claims are also made for its use in preventing smallpox (seeds) and in treating chronic colds, diabetes, inflamed testicles, swollen limbs, and stomach troubles (leaves). The same writer (Hurov) reports buds and flowers contraceptive when taken during the menstrual period.

There may be some basis for such claims of antifertility activities of the flowers. In reviewing work on indigenous Indian plants for fertility control, Nagarajan et al. (1982) summarized results of several articles in which extracts of flowers (but not of leaves) of S. sesban resulted in antifertility activity in rats and mice (Bhaduri et al., 1968) and were cited as abortifacients in mice (Pakrashi et al., 1975). The latter authors reported the belief in India that the taking of flowers for three days during menstruation inhibits conception. They fed extracts to pregnant mice at 50 mg extract per kg body weight on day one and day six of pregnancy, and found abortifacient activity ranging from 54-77% depending on the type of extract.

There are several references to use of sesbania leaves as a galactagogue to stimulate or increase the secretion of milk. Ochse (1931) stated that in Java leaves and young pods of S. grandiflora are eaten, especially by nursing mothers. According to Brown (1954), feeding these leaves to cattle is believed to increase their milk production. The Haya people of Africa use S. sesban similarly. Hurov calls S. sesban the "Kenya milk shrub."

Antitumor activity has been reported for the North American species S. drummondii, and brief reviews of this work have recently been published in popular scientific press (Anon, 1983; Garmon, 1983). This characteristic was revealed when Powell et al. (1976) reported that ethanolic seed extracts of S. vesicaria, S. punicea, and S. drummondii were cytotoxic in the KB cell culture and were active against lymphocytic leukemia P-388 in mice. Fractionation of S. vesicaria resulted in enrichment of the active portion, but it was not possible at that time to associate the antitumor activity with any constituent. Later, Powell et al. (1979) described the isolation of a cytotoxic compound from an ether extract of S. drummondii which was given the name sesbanine. The compound has no close structural relatives. Further fractionation revealed a second compound, drummondol (Powell and Smith, 1981). Because 450 kg of seed yielded only 50 mg of pure sesbanine (Powell et al., 1979), efforts to synthesize the substance were initiated; recently they cited four groups having produced a synthesis before 1981 (Powell et al., 1983), and Wanner et al. (1982) have published an additional report. Synthetic sesbanine is said not to have shown activity in experimental tumor systems (Powell et al., 1983). However, that work reported that fractionation of sesbanine has revealed an "exceptionally potent antitumor compound," sesbanimide, having an unusual tricyclic structure with single bonds linking the rings. Similarity in structure with glutarimide antibiotics has raised the question of whether sesbanimide is a true plant product or a metabolite of a microorganism associated with the plant. In National Cancer Institute tests, sesbanimide given to mice at 0.01 mg/kg body weight resulted in a 171% increase in survival time compared to control leukemics which did not receive it; other tests *in vitro* have demonstrated inhibition of human carcinoma cell growth (Garmon, 1983; Anon, 1983). Synthesis of sesbanimide has not yet been accomplished (Powell, personal communication, 1983).

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10. RHIZOBIUM RELATIONSHIPS IN SESBANIA SPECIES.

Rhizobium bacteria which nodulate *Sesbania* species are fast-growing strains. Isolates of these bacteria to not appear to be very stable when stored in culture, and they tend to lose viability (B.B. Bohlool, personal communication). Frequent transfer of cultures, maintenance of appropriate storage temperatures (refrigeration may not be appropriate), and buffering the culture media against shifts toward lower pH may be tactics to promote culture maintenance, but there have been no reported experiments to find the proper conditions. Some physiological responses of rhizobia isolated from sesbanias to certain stresses have been studied by Indian scientists, including the effects of *Streptomyces* spp (Oblisami & Rangaswami, 1967), 2,4-D (Pareek & Sidhu, 1978), and molybdenum and copper (Singh et al., 1975).

Studies on sesbania nodules include research on the absorption spectra and behavior of *S. cannabina* leghemoglobins (Thakkar & Vyas, 1972, 1973, 1975), and a report on the relation between sugars and bacterial invertase in developing nodules on *S. grandiflora* (Singh et al., 1980). Mathur and Singh (1971) studied the effects of seed treatment with various pyrimidine bases and their analogues on subsequent nodulation of *S. bispinosa*. Khurana and Vyas (1976) used gel electrophoresis to study and compare isozymes in bacteroids from nodules of sesbania, *Cicer*, and *Pisum*. Sen (1969) described morphogenesis of nodules of a number of legumes including *S. sericea*. A more specific study of infection and development of nodules on *S. sesban* roots was done by Mahmood and Jamal (1977), and Tang et al. (1980) used electron microscopy to study and compare the stages of the infection process in *S. cannabina*, *Glycine max*, *Pisum sativum*, and *Phaseolus vulgaris*.

Cross-inoculation relationships between *Rhizobium* of *Sesbania* and those of other legumes have been the subject of a number of studies. Date and Halliday (1980) categorized the *Sesbania*-*Rhizobium* symbiosis as "promiscuous but often ineffective," but did not give references or data in support of this view. The general implication of the literature, confirmed by our observations (Evans, and Evans & M. Habte, unpublished) is that *Sesbania* species vary considerably in their ability to be nodulated by specific strains of *Rhizobium*, and there is host-strain specificity within the genus.

Recent work by Gaur and Sen (1978, 1979) revealed a relationship between *Sesbania* and *Cicer* symbioses. Of 71 *Cicer* isolates tested on 89 legume species, including *C. arietinum*, 18 nodulated only *S. bispinosa* and *S. sesban*. Of 287 isolates obtained from 52 legume species (not including *Cicer*), the only isolate nodulating *C. arietinum* was one from *S. bispinosa*. The authors observed that in field conditions, the "loose, non-reciprocal kinship of *Cicer* with *Sesbania*" was rare. Other recent investigations by Trinick (1980) studied the relationships among fast-growing isolates of various legumes including *S. grandiflora*. Trinick and Galbraith (1980) found that *S. grandiflora* isolates, as well as isolates from *Leucaena leucocephala*, *Mimosa pudica*, and *Lablab purpureus*, nodulated the non-legume *Parasponia*, with low levels of N-fixing activity. Earlier work by Trinick (1968) had nodulated *L. leucocephala* with *S. grandiflora* isolates, but the symbiosis was ineffective. Oblisami (1974) studied a *Clitoria ternatea* isolate which nodulated *G. max* and was able to produce nodules on cowpea and on sesbania to a greater extent than on its original host. *Clitoria* was not cross-compatible with the bean, pea, clover, or alfalfa cross-inoculation groups, but was nodulated by isolates from *S. bispinosa*, *Crotalaria juncea*, *G. max*, and cowpea. Ishizawa (1972) has also compared cross-inoculation characteristics of *Sesbania*, *Leucaena*, and *Mimosa*. Sanogho (1977) studied isolates of the African species *S. letocarpa* and *S. pachycarpa* in compatibility tests with other legumes of the Lido Valley of Mali.

Earlier studies on cross-inoculation in *Sesbania* were done by Wilson (1939), Briscoe and Andrews (1938), Raju (1936, 1938), Hoge (1939), and Harris (1941). Most of these studies involved a number of legume genera. Suggestions by Raju and by Briscoe and Andrews to establish a "dhaincha" or "sesban" inoculation group of *Rhizobium* were not widely accepted. Raju pointed out that *Sesbania* strains were somewhat effective on cowpea, but *Sesbania* was in general nodulated only by its own isolates. Other authors including Gaur and Sen (1979) have also commented on the affinity of *Sesbania* with the "cowpea miscellany." Wilson (1946) made the interesting observation that isolates from one *S. exaltata* plant were not necessarily capable of producing nodules on plants from seed of a different *S. exaltata* plant; he suggested that this was genetic variation resulting from cross-pollination, incompatible with the Linnaean concept of a species.

Johnson and Allen reported cultural (1952a) and nodulation (1952b) studies which revealed differences in strain growth characteristics and marked host specificity in strains isolated from different Sesbania species; isolates from the north american species S. macrocarpa (=S. exaltata) showed cultural characteristics different from isolates from S. grandiflora, S. bispinosa and S. sesban (3 pantropical species), and S. tomentosa (a Hawaiian endemic). The cowpea affinity was again observed, as Sesbania isolates nodulated common beans and cowpeas, but without reciprocity.

Some studies of the salt tolerance of Sesbania species have focussed on the tolerance of their associated Rhizobium symbionts. Bhardwaj (1974a) found that of 9 saline-alkali soils from 3 states in N. India, all had strains which nodulated S. bispinosa. Bhardwaj (1972) had previously noted that strains isolated from saline-alkali soil survived more readily when incubated in highly saline-alkali soils than did strains from non-saline-alkali soils. Comparing different legumes, Bhardwaj (1974b) found that sesbania was more frequently nodulated under field conditions than were Melilotus parviflora, Trifolium alexindrinum, Cyamopsis tetragonoloba, Vigna unguiculata, Lens esculenta, and Pisum sativum (listed in decreasing order of nodulation incidence and nodule number/plant); strains isolated from sesbania were judged more effective than those from the other species. Additions of gypsum with either farmyard manure or sesbania green leaf manure were found to enhance growth of these strains of rhizobia introduced to sterilized soil. 20% of the strains isolated from sesbanias in saline-alkali soils were pigmented, v.s. 4.5% in normal soils, suggesting correlation between pigmentation and salt tolerance (Bhardwaj, 1972b).

Yadav and Vyas (1971, 1973) found sesbania isolates more tolerant of salts and alkalinity than isolates from *Glycine max* and *Crotalaria juncea*. The strains all grew well at pH 10 but were sensitive to pH 3.5-4.0.

While *Rhizobium* apparently can tolerate high pH and salt concentrations, legume symbiosis is generally inversely effective with increases in these conditions. Singh and Rai (1972) found decreased nodulation in both *S. bispinosa* and *Melilotus alba* as salinity and especially alkalinity increased, although these declines were ameliorated by phosphorus applications. Comparing 10 cultivated legumes, most had substantially reduced growth and nodulation as a result of increasing soil ESP, with a maximum of ESP 34 for most of them, but sesbania and *M. parviflora* could grow and be nodulated at ESP 70; however, even in these tolerant species, development of nodulation was delayed.

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11. SESBANIA ROSTRATA: A SPECIAL CASE.

Among the remarkable qualities of growth and tolerance displayed by species of *Sesbania*, the almost singular peculiarity of one species stands out. *Sesbania rostrata*, native to tropical West Africa, supports nodules on its stem and branches as well as on its roots. This relatively unique phenomena is also noted in some *Aeschynomene* species (Arora, 1954). Research on this symbiosis in *S. rostrata* and its agronomic implications has been conducted by scientists at the Office de la Recherche Scientifique et Technique, Outre-Mer et Centre National de la Recherche Scientifique at Dakar, Senegal, from whose reports most of the information following has been derived.

Sesbania rostrata (Brem. and Oberm.) is an annual legume which has been described by Berhaut (1967). Its distribution, according to Gillett (1971), is from Senegal to Sudan, Congo (Katanga), Zaire, Malawi, Rhodesia, Botswana, Caprivi Strip, Madagascar, apparently always local and never abundant. It normally grows during the hot, summer season (June to September) in the Senegal Valley when moisture is plentiful, and like many other sesbanias, as a natural habitat it prefers low-lying, moist soils which are frequently waterlogged and occasionally inundated. During its vegetative growth period, generally 2-3 months long in the summer months, it may reach heights of 5 m before entering its reproductive phase. However, when cultivated during the cool, dry season centered on the period from December to Feburary, growth is poor and quickly interrupted by flowering, probably due in part to the shorter photoperiod during these months at 15 degrees north latitude in Senegal (Dreyfus et al., 1983).

Stem nodulation as it occurs naturally in S. rostrata is not well characterized. Nodulation can occur at any height on the stem, although not all of the prospective sites of nodulation are always invaded by Rhizobium and nodulated. Nodule mass on a well-nodulated S. rostrata plant may amount to 15-40 g fresh weight per plant, and specific nodule activity as measured by acetylene reduction is comparable to nodules of soybeans and cowpeas (Dreyfus & Dommergues, 1981). The method by which the rhizobia reach the stem sites is not known, but it is suspected that dust is an agent, since plants on the borders of stands of S. rostrata in Senegal were observed to be more extensively nodulated. Experimentally, dilute cultures of Rhizobium are sprayed or painted on the stems. Temperature and humidity apparently play a role in the infection process, since during the winter months in Senegal infection is difficult to achieve, while during the summer, it is difficult to maintain control plants unnodulated (Dreyfus et al., 1983; Rinaudo et al., 1982). Possibly, under natural conditions stem nodulation occurs only in waterlogged plants.

The sites of infection are root primordia which first appear as small swellings, usually less than 1 cm apart in rows, and there are 3-4 or more rows on all stems and branches. As the stems develop, the apex of the root initial pierces the epidermis at these sites, and this rupture is the point of access for rhizobia. When the stems are flooded, adventitious water roots arise from these meristematic sites; otherwise, they may become nodule sites. Even after development of a nodule, the latent root apex may begin to grow if that portion of the stem is flooded (Duhoux & Dreyfus, 1982). The process of infection has been investigated and described by Tsien et al. (1983) and Duhoux (1984). Similarly to the infection process in groundnut (Arachis hypogaea) roots, rhizobia enter the plant via intercellular spaces rather than through infection threads formed by cell wall invagination of curled root hair tips, as is the case with most other legumes. Differing from groundnut, rhizobia entering S. rostrata cytoplasm from intercellular spaces do so by an intracellular invagination similar to an infection thread. The cells thus penetrated are described as a highly meristematic, cortex-derived tissue surrounding the base of the root primordium.

Rhizobium characteristics in the S. rostrata symbiosis are also unique. The strain isolated and described by Dreyfus and Dommergues (1981), ORS 551, is apparently capable of fixing N in its free-living state, since cultures grow when given N2 or ammonia as sole N source. Because these strains can be selected in culture for N-fixing ability or lack thereof, they offer opportunities for genetic studies such as have been reported by Elmerich et al., 1982. When in developed stem nodules of experimental plants grown hydroponically, these bacteria fix atmospheric N despite the presence of combined N in the root zone, but when in root nodules, N fixation (as indicated by acetylene reduction) was inhibited by combined N. N in the root zone actually enhanced acetylene reduction in stem nodules (Dreyfus & Dommergues, 1980). The implications of this ability are important, since most legumes tend to take up available soil N preferentially, and fix large amounts of atmospheric N only when soil N is depleted in the root zone.

The Rhizobium nodulating S. rostrata stems is fast-growing and highly specific. ORS 551 nodulated other Sesbania species, but not effectively, while isolates from S. pachycarpa likewise produce ineffective nodules on S. rostrata roots. Cowpea isolate CB 756 and isolates from Aeschynomene sp. stem nodules would not nodulate S. rostrata roots, and ORS 551 did not nodulate roots of Aeschynomene or of Macroptilium autropurpureum (Dreyfus & Dommergues, 1981). Strains from S. rostrata which nodulate its stems will also nodulate its roots, but not all root-infecting strains will nodulate stem sites. Dreyfus et al. (1983) refer to 3 types of nodules occuring on S. rostrata: the stem nodules, and 2 types of root nodule, one of which occurs at the root crown just beneath the soil surface, has terminally meristematic lobes, and is 2-15 mm long, and the second of which is spherical, 1-2 mm in diameter, and is found along lateral and adventitious roots. The first type of root nodule disappears upon flooding, perhaps because since S. rostrata does not develop aerenchyma as extensively as do most Sesbania species when flooded (Evans, observation), and lacking this tissue the nodules can no longer function. However, the second type of root nodule proliferates upon flooding. All types of nodules have green epidermal tissues, including those near the soil surface.

Similar nodule morphologies were noted on S. rostrata plants grown in Hawaii, but we were not able to effectively nodulate roots or stems with cultures isolated from a number of other Sesbania species (Evans and M. Habte, unpublished data). Grown in soil, lobed root nodules occasionally developed on some -- but not all -- S. rostrata plants, and some of these nodules seemed effective by the presence of leghemaglobin and by plant color. Isolates from such nodules did not infect stems or reinfect roots. The small round nodules which developed on floating roots were often lacking leghemaglobin. Some apparently ineffective stem nodules were obtained after painting stems with fresh, crushed nodules from a different Sesbania species. Grown in field trials, S. rostrata had low N content compared to other sesbanias, and did not appear to be effectively nodulated even though inoculated with strains highly active on other species (Evans & Rotar, in preparation).

The use of N fixed by S. rostrata to benefit associated non-legume crops was tested in a "preliminary" experiment, widely published in various forms (Rinaudo et al., 1982a&b; Dommergues, 1982; Rinaudo et al., 1983; Dreyfus et al., 1983). S. rostrata was grown at a population of 400,000 plants/ha (i.e., about 16 cm apart) during the summer in Senegal, kept under flooded conditions for most of its growth period, and inoculated twice (21 and 30 DAP) by spraying stems with ORS 551. One month after the first inoculation (about 50 DAP), when 1.5 m tall, the plants were cut into 10 cm segments and incorporated into the soil, which had not been irrigated during the previous week. About 2 weeks later, rice seedlings were transplanted at a population of 250,000 hills/ha, flooded, and grown for 120 days.

In plots where the legume was not grown or incorporated, yields were increased by about 70-80% when NPK (N at 60 kg/ha) was applied, v.s. controls receiving only P and K. When the legume was applied (also with P and K), yields were increased by about 170-180% over control yields without added N (Rinaudo et al., 1982). Plant N content was also significantly increased, and total N uptake in green manured rice was more than double that of rice receiving 60 kg/ha inorganic N. The authors extrapolated that soils of lower than average fertility could support rice grain yields of 6 Mg/ha with PK fertilizer and S. rostrata green manure (Rinaudo et al., 1982b).

The experiment was conducted in microplots measuring 1 m square by 50 cm deep, separated by concrete walls and rendered watertight with polyethelene sheet plastic; each contained 560 kg soil, a sandy Ustropept. Based on a comparison of plots receiving no N with plots green manured, in regard to increases in rice N uptake and soil N content following the rice crop, the authors estimated (Rinaudo et al., 1983) that S. rostrata fixed at least 267 kg/ha N. They estimated that yield increase of rice was equivalent to that obtainable from a surface aplication of 130 kg/ha N as ammonium sulfate (assuming 57% efficiency). Of the N fixed, about 1/3 was transferred to the following rice crop and 2/3 remained in the soil. The following year, rice grown in the microplots showed yield increases 50% over the no-N controls as a residual effect of the green manure treatment (Dreyfus et al., 1983).

Above-ground dry matter yield of the 52-day S. rostrata crop was given as approximately 20 Mg/ha (Dreyfus et al., 1983), representing a dry matter accumulation rate of 385 kg/ha/day. This calculated rate is about the same as the average fresh weight accumulation rate reported in the literature for S. bispinosa green manure crops. Grown in a yield trial in Hawaii at a population of 125,000 plants/ha, S. rostrata produced 12 Mg/ha dry matter in 14 weeks, indicating a much lower dry matter accumulation rate of 122 kg/ha/day (Evans & Rotar, in preparation). In that experiment, S. rostrata was apparently not effectively nodulated on its roots, and it had no stem nodules; it contained only 79 kg/ha N in its above-ground yield, and it had the lowest leaf/stem proportion of both dry matter and nitrogen of 35 Sesbania accessions grown. Despite these characteristics, its dry matter yields were within the range of the higher-yielding varieties, 8-17 Mg/ha.

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12. WEED STATUS AND CONTROL.

Occurrence of Sesbania species as weeds.

Sesbania species, especially annuals, have the potential to become weeds in field crops. They may compete with crops for light, nutrients, and moisture and thus reduce yields; heavy weed growth may interfere with crop harvest by hampering machinery; and sesbania seeds may contaminate harvested grain, reducing its value. Most of *Sesbania*'s reputation as a weed is derived from experience with *S. exaltata* in North America, but a few other species have been noted elsewhere in the world. *S. punicea* has recently been declated an exotic weed in S. Africa (Anon., 1980). Native to the Old World, this woody shrub was an ornamental plant which escaped from gardens (Taylor, 1974) and quickly became naturalized to the extent that it began replacing indigenous vegetation (Stirton, 1978). Although of widespread occurrence, it was not ranked among the top 5 most important and aggressive woody plant invaders (Wells et al., 1980), but Erb (1979) cautioned that the plant had "by no means reached its natural limits." In Nigeria, *S. bispinosa* has been noted as a weed of experimental plots (Yayock, 1976). In Australia, *S. cannabina* infests crops of cotton (Kolomyjec et al., 1979) and sorghum: a population of 28 plants/m2 reduced sorghum grain yield by 19% (Rawson & Bath, 1981). *S. exasperata* persists in lands converted to rice cultivation in Surinam (De Wit, 1960), while in neighboring Guyana the similar species *S. sericea* occurs in dry-sown rice fields, but does not occur in fields sown and maintained in flooded condition

(Kennard, 1973). In India's Punjab, S. bispinosa was among maize field weeds whose occurrence, populations, and growth periodicities were studied by Bir & Sidhu (1975). Another study from Madhya Pradesh, India, tested herbicides to control this species in soybeans (Shrivastava et al., 1976). Considering how widely S. bispinosa is grown as a green manure crop in India, it is remarkable that we have not discovered more references to its weed status there. It is possible that its presence is welcome in intensively managed fields for the nitrogen which it will fix. In Africa, S. pachycarpa volunteers in sorghum fields where its growth is sometimes encouraged (Gillett, 1971).

Sesbania exaltata (=S. macrocarpa) is a widespread weed of crops in the southern United States. It is a major problem in soybean growing areas, capable of causing 60-80% yield reductions (Lunsford et al., 1976). It is also a serious weed pest in cotton, sweet potatoes, and rice; its occurrence was noted in 53% of rice fields in Arkansas (Baldwin et al., 1977). It does not appear to be a problem in maize in the U.S., perhaps because of the highly effective pre-emergence herbicides (such as atrazine) used with maize (Crawford & Rogers, 1979), and the inclusion of such maize crops in rotations is considered an effective method of reducing the magnitude of infestation of cotton crops (Dale and Chandler, 1979).

Growth studies with Sesbania species.

Studies on the germination and growth of sesbanias have been done in the context of effecting their control. Variations in germination with differing soil temperatures, moisture levels, and depths of seed below the soil surface have been studied in S. exaltata (Smith & Fox, 1973; Eastin, 1981; Jolley & Murray, 1978; Walker et al., 1979) S. sesban (Rijn & Verhagen, 1980), and in S. sesban, S. grandiflora, S. microcarpa, and S. bispinosa at differing moisture stress levels after varying storage periods (Pathak et al., 1976). S. exaltata has been included in a 50-year study of seed longevity initiated in 1972 (Egley & Chandler, 1978). Egley & Williams (1979) found that cultivation to a depth of 15 cm reduced grass weed populations but had no effect on emergence of S. exaltata. Seed germination at varying osmotic potentials has been studied, and compared to soybeans, S. exaltata was more tolerant to induced moisture stress. Soybean germination was reduced at -2 bars, but an osmotic potential of -4 bars or more was required to reduce sesbania germination (Johnson et al., 1979; Williams, 1980). Bailey et al. (1980) studied exaltata's phenological development, and Patterson et al. (1978) measured growth parameters at varying light intensities.

S. bispinosa seed imbibition after soaking 24 hours was low compared to seeds of 40 other plants of India's arid Rajasthan area (Bansal et al., 1980). Sharma et al. (1978) reported differential seed coat dormancy in this species, which emerges with the monsoon rains in July and August, begins seeding in September, and continues setting seed until about February. Seeds set in the first flush of seeding had 100% germination without scarification, but seeds set in later, drier periods (October, November) would not imbibe without scarification. The earlier collection subsequently underwent a change in seed coat permeability, becoming less permeable. Seed weight decreased with later settings. Different collections required soaking in concentrated sulfuric acid for periods of 15-45 minutes to obtain 100% germination, with these soaking times increasing for seeds set later in the growth period.

Protein synthesis is one element of plant physiology affected by herbicides. Dubey (1979) tested 10 herbicides and found that some increased, some decreased, and some did not affect protein synthesis in S. bispinosa. Mann et al. have published a number of articles on their work with S. exaltata (1965 a&b, 1967 a&b, 1968), and Baxter (1976) has reviewed research on protein synthesis as affected by herbicides in Sesbania, soybean, and barley.

The extent of competition of S. exaltata with soybean crops was studied experimentally by McWhorter & Anderson (1979). Soybean yields were not reduced by S. exaltata populations between 1600 and 5500 plants/ha throughout the growing season, but between populations of 8100 and 129,000 plants/ha, yields were reduced 10-80%. If relatively high populations of sesbania (68,000 plants/ha) were controlled within 4 weeks of soybean emergence, then yields were not seriously affected, but if competition continued for 6, 8 or 10 weeks, yields fell by 18, 27, and 43%, respectively. The period from the 6th to 10th week after soybean emergence was regarded as the most critical period for control of

S. exaltata. Walker et al. (1979) have also studied competition effects of *S. exaltata* allowed to compete with soybeans for the full growth season, and found that yield reductions were less when soybeans were grown in 61 cm rows than in 91 cm rows, even when more sesbania plants were present.

Control of S. exaltata with herbicides.

Because of the importance of soybeans as a crop in the U.S., a sizeable number of research reports have been published on herbicides for control of *S. exaltata*. Control is complicated by the fact that both are broad-leafed legumes, and soybean may also be sensitive to the same herbicides. Variations in application rates are necessitated by differing soil types in the case of pre-emergence herbicides and in the case of post-emergence sprays, the relative susceptibility to damage of the soybean crop at different soybean growth stages. The growth stage of sesbania is also a determinant of effectivity of control, being generally less sensitive to herbicides as growth progresses.

The herbicide acifluorfen applied as a post-emergence spray is effective in controlling *S. exaltata* (Laurence et al., 1978 a&b; Barrentine, 1978; Rogers & Crawford, 1980). Good control with acifluorfen is obtained with applications of 280 g/ha (0.25 lb/acre), which is often applied in tank mixtures with 840 g/ha (0.75 lb/acre) bentazon for control of major broadleaf weeds (Helpert & Viar, 1983). An application rate of 140 g/h applied before bloom stage of sesbania was effective (Mathis, 1980), as was 150 g/ha applied between the 1- and 7-trifoliate leaf stage of soybeans (Rogers & Crawford, 1980). Porter & Retzinger (1983) tried lower rates of 28 or 56 g/ha at different spray volumes (47, 187, or 374 l/ha) and surfactant concentrations, and obtained an average of 93% control of S. exaltata at either rate and all volumes when the highest concentration (1%) of surfactant was used. Soybeans in the 3- and 6-trifoliate leaf stage sprayed with acifluorfen at rates of 140-1120 g/ha were injured but recovered in 14 days (Mathis, 1980). Yih (1979) found it effective at rates of 110-560 g/ha at al soybean growth stages, and stated that groundnut and some beans also tolerated postemergence treatment with acifluorfen. Lee and Oliver (1979; Oliver & Lee, 1979) found that better S. exaltata control was obtained by spraying acifluorfen at dusk or evening than at dawn or at noon, especially when low application rates were used.

Mefluidide (formerly MBR 12 325) is a postemergence herbicide for control of johnsongrass and volunteer maize and sorghum, and is also used in tank mixes with other herbicides, notably bentazone, to control S. exaltata (Nester et al., 1978; Murray et al., 1978b; Harger et al., 1979). Viar and Atwell (1980) showed that neither mefluidide at 280 g/ha nor bentazone at 840 g/ha could control sesbania >10 cm high, but the two combined (even at lower rates) provided excellent control of sesbania plants up to 90 cm high. Rogers & Crawford (1976) showed that surfactants increased control levels obtained with bentazone at rates from 840-1680 g/ha, and temporary injury to the soybean crop increased proportionately to the extent of control. Mefluidide has been used to control *S. exaltata* sprays with either nonoxynol, dinoseb, or naptalam + dinoseb in directed sprays (McWhorter & Barrentine, 1979); with acifluorfen (each at 300 g/ha) for sesbania 10-40 cm high (Lawrence et al., 1978b); and with chloroxuron (Hargroder et al., 1977; Gates, 1976). Both bentazon and chloroxuron (at 1120 g/ha) were effective against *S. exaltata* in soybeans as overall sprays (Murray et al., 1978). Mefluidide by itself acts to kill the apical meristem and axillary buds, but may not kill entire plants unless combined with other herbicides with resulting additive or synergistic effects; applied at flowering and pod setting, it suppresses seed formation in *S. exaltata* (Gates, 1975, 1976).

A pre-emergence herbicide for control of *S. exaltata* is metribuzin, a substance which is more actively translocated and less actively metabolically degraded in sesbania than in soybean (Hargroder & Rogers, 1974). Metribuzin has shown good control applied pre-emergence at 420 g/ha (English & Oliver, 1980) or at 500 g/ha (Murray et al., 1978). It may also be applied postemergence as a directed spray (Glover et al, 1979). Barrentine (1975, and Barrentine et al., 1979) tested different application timings and incorporation methods for metribuzin + trifluraline Metribuzin has also been used in combination with alachlor (Scudder, 1977), oryzalin (Watson et al., 1974) and linuron (Eastin, 1973; Lawrence et al, 1978a).

Other herbicides used against *S. exaltata* in soybean crops are 2,4-D applied with absorbent bar (Crawford, 1971) or directed spray (Harger et al., 1979), and glyphosate applied (at 1680 g/ha) using a recirculating sprayer method in which herbicide is applied only to weeds (McWhorter, 1977). A similar method may be used to apply acifluorfen (Barrantine & Reames, 1980. Glyphosate applied to soil has been shown to reduce plantlet growth during post-germination stages, but to a lesser degree in S. exaltata than in other species tested (Hoagland, 1977). Pre-emergence herbicides tested to control S. bispinosa among soybeans in India were chloramben, alachlor, nitrofen, and chloroxuron (Shrivastava et al., 1976).

Phenisopham has been used as a postemergence spray in cotton to control S. exaltata; it is effective on seedlings of the cotyledon and 2-pinnate-leaf stages, but not at the 6-leaf stage or above (Kolomyjec et al., 1979; Roca et al., 1979).

In rice crops, R-40 244 herbicide applied postemergence at 560 g/ha controlled S. exaltata in drill-sown rice (Baker, 1978). Postemergence sprays of oxadiazon and mixtures of propanil + oryzalin, or + nitralin, or + butachlor, or + oxadiazon gave 80-100% control of weeds including S. exaltata in rice with only slight damage to the rice. Tank mixtures of propanil + benthiocarb were also effective, and molinate was substituted for propanil with benthiocarb, butachlor, and ozadiazon (Smith & Fox, 1971; Smith, 1972, 1973).

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13. INSECT PESTS AND PLANT DISEASES AFFECTING SESBANIA SPECIES.

Tables 1 and 2 summarize reports of insects and plant diseases associated with Sesbania species. In general, interest in pests of sesbanias in India arises from a desire to protect the crop, while interest in the Americas is biased in favor of the predator. Thus, for example, work such as that of Erb (1979) in Argentina and of Berg (1981) is motivated by interests in identifying suitable biological controls for S. punicea.

Pests which may affect sesbanias and limit productivity as crops are leaf webbers and other leaf feeders, and stem boring pests. Because of the rapid growth of many sesbanias, annual species in particular, a crop may offer large amounts of succulent stems for infestation during its exponential growth phase. In Sesbania species accession observation trials in Hawaii, we have observed some minor incidence of stem pests, and also of leaf webbers. Leaf chewing pests have not been common in Hawaii on most species, although some of the reports from India indicate severe defoliation as a result of pest population increases which may be localized spacially and temporally. One species which sustained leaf damage from chewing pests in Hawaii was the perennial S. formosa, the only one of several perennials tested which did not prove toxic when leaves were fed to chicks (see section on toxicities).

Another category of pest noted in Hawaii are seed pests. Surprisingly, rather few references to such pests are found from India, where large amounts of seed are produced for green manure crops requiring high sowing rates. One report (Sharma et al., 1978) stated that in Rajasthan, India, naturally occurring *S. bispinosa* germinated with the onset of monsoon rains in July, began flowering in September, and continued flowering and setting seed through the following February, but in December, a pod pest (unidentified) infested the plants and seed set thereafter was damaged.

In Hawaii, introduction plantings have been infested with a seed chalcid, and infestation has varied in severity among species. The adult oviposits on developing pods, the larvae develop within the developing seeds, consuming the interior portion, and exit as adults after making a hole about 1 mm in diameter in the seed coat. Some species such as *S. macrantha*, *S. speciosa*, and *S. tetraptera* were not infested, *S. sesban* was moderately infested, but *S. grandiflora* and most members of the bispinosa-cannabina-sericea species group were infested to the extent that only 5-10% of the seed collected was entire. The seed chalcid pest was identified by Dr. Carl Yoshimoto at the Canada Department of Agriculture, Ottawa, as *Bruchophagus mellipes* Gahan, and had not previously been known in Hawaii (Beardsley, 1983). Gahan (1920) described the pest as a new species, which had been received from Coimbatore in southern India and had been previously identified as *Eurytoma indi* (Girault) Ramakrishna Ayyar. Although related to *B. roddi*, the alfalfa seed chalcid, *B. mellipes* did not seem to infest alfalfa plants growing nearby at the site of our sesbania plantings. Searches of Commonwealth Agricultural Bureaux

(CAB) and U.S. National Agricultural Library bibliographic databases did not reveal any literature relating to B. mellipes. It is possible that in India, parasites and predators keep infestation by these chalcids at low levels; in Hawaii, the pests may be of recent introduction and thus populations developed unchecked by biological controls.

Sclerotium rolfsii has caused wilt in several accessions of S. sesban during unusually dry weather in Hawaii. This occurred in a fodder cutting experiment where the trees, planted 25 cm apart in rows 1 m apart, were cut back to a height of 50 cm every 7-8 weeks. Cumulative incidence of wilt over a very droughty 3-month period in months 10-12 of the experiment varied from 5-50% of the plants in individual plots of 4 5-m rows, and wilt was observed to occur especially after cuttings. Each harvest removed almost all of the foliage, which undoubtably increased soil temperature and encouraged colonization by the fungus at a time when the plants were weakened. In such fodder production schemes during dry periods partial selective cutting to maintain shade for the soil surface and reduce shock to individual plants may be a way to avoid susceptibility to such wilts.

There is very little information on chemical control of insect pests in sesbania crops. In Hawaii we have used carbaryl and acephate (Orthene TM) to control aphids and leaf webbers. Acephate was thought preferable because of its moderate residual systemic activity, but the extent to which it reduced seed chalcid activity in uncertain. Recommendations originating from outside the U.S.A. of substances for pest control in sesbanias often specify materials such as DDT and BHC, which are no longer permitted in the U.S.A. and should not be considered for use elsewhere.

Only limited work on biological control of pests of *Sesbania* species has come to our attention. Sithanantham (1970), observed *Aspergillus tamarii* as a pathogen on the Sesbania stem borer. Cherian and Brahmachari (1941) reported on insects which were predatory on caterpillars infesting *S. bispinosa*.

Nematodes.

With the exception of 2 articles, all other references to plant-parasitic nematode infestation of *Sesbania* which we have found concern the North American species. *S. exaltata*. In India, Jain (1981) found that *S. microcarpa* was susceptible to invasion by *Meloidogyne incognita*. Germani et al. (1983) in Senegal studied the effect of a preceeding *S. rostrata* crop on reducing subsequent infection of rice by *Hirschmaniella oryzae*, and suggested that the legume may have acted as a trap crop.

In the United States, *S. exaltata* grows very rapidly during hot summer weather, and one report (USDA, 1935) stated that good stands often result despite nematode infestation, although following crops may be severely attacked by nematodes harbored in the sesbania crop roots. Soffes (1981) found, in contrast, that *S. exaltata* was extremely sensitive to infestation with root-knot nematode (*M. incognita*), such that soil fumigation to control the pest increased plant dry matter yield by > 10 times, and N yield by >20 times the yield of plants in unfumigated plots. *Lablab purpureus* and *Vigna radiata* were also hosts with reduced yields which increased soil root-knot nematode populations, whereas *Indigofera hirsuta*, *Cajanus cajan*, and *Crotalaria spectabilis* yields were not severely reduced by nematodes. Rhodes (1964) showed that nematode populations were supported by sesbania or weedy fallow and suppressed by *C. spectabilis*, and yields of snap beans and cabbage were higher following the latter. Even when soil fumigation followed the legume crop, Rhoades (1968) observed that stubby-root nematode (*Trichodorus* spp.) populations returned in greater numbers adfter sesbania than after crotalaria. In further studies, Rhoades (1976) found that sesbania and sorghum maintained sting (*Belonolaimus longicaudatus*) and root-knot nematode populations, but *I. hirsuta* decreased them, and snap beans following these crops yielded 5.6, 3.4 and 8.9 Mg/ha pods, respectively. In this study, yields after *I. hirsuta* were the same as those after sesbania followed by soil fumigation with D-D at 260 l/ha. Overman (1969) also had identified sorghum and *S. exaltata* as hosts of the sting nematode, as evidenced by higher levels of infestation in a following chrysanthemum crop and lower cut-flower yields compared to the crop following *I. hirsuta*. Epps & Chambers (1958) found the soybean cyst nematode (*Heterodera glycines*) on *S. exaltata*, but believed that sesbania may not be a preferred host of this pest.

Table 1. Insect pests of *Sesbania* species

Pest	Location	*Sesbania* Species Affected	Comments	Reference
Eudiagogus spp	New World	sp.	adults defoliate	Warner, 1979
E. rosenchoeldi Fhs.	Mississippi	exaltata	larvae attack roots and nodules	Warner, 1979
E. pogo	Georgia, USA	exaltata	adults defoliate	Warner, 1979
E. maryae	Florida, USA	exaltata	adults defoliate	Warner, 1979
Rhyssomatus marginatus	Argentina	punicea, virgata	beetles feed on fruits	Erb, 1979
Apion decipiens	Argentina	punicea, virgata	seed feeder	Erb, 1979
Diplogrammus quadrivittatus	Argentina	punicea, virgata	stem borer	Erb, 1979
Dasychira mendosa Hb.	Tamil Nadu, India	speciosa	alternate host	Rao & Bucker, 1974
Indarbela quadrinotata Wlk.	Haryana, India	cannabina	orchard pest, alternate host	Verma et al., 1974
Bruchidius spp.	NW India	spp.	larvae develop in seeds	Vats, 1977
Euprocitis scintillans	Tamil Nadu, India	cannabina	pulse crop pest, alt. host	Rao et al., 1974
Azygophleps scalaris Fabr.	U.P., India	bispinosa, sericea, sesban, grandiflora	stem borer	Srivastava & Gupta, 1967 Agarwal & Agarwal, 1960

Azygophleps scalaris Fabr.	Tamil Nadu, India	bispinosa, sericea, sesban, grandiflora	stem borer	Venugopal & Rao, 1961
Dacus cucurbitae	Hawaii	grandiflora	larvae develop in flowers	Nakagawa & Yamada, 1965
Dacus dorsalis	Hawaii	grandiflora	larvae develop in flowers	Nakagawa & Yamada, 1965
Maruca testulalis	Hawaii	grandiflora	bean pest, alt. host	Nakagawa & Yamada, 1965
Lampides boeticus	Hawaii	grandiflora	bean pest, alt. host	Nakagawa & Yamada, 1965
Striglina scitaria Wlk	Tamil Nadu, India	bispinosa	larvae web & feed on leaves	Venugopal 1959b, 1960
Selenis monotropa	Florida, USA	exaltata	soybean pest, moth attacks stems	Genung & Green, 1965
Alfalfa caterpillar	California, USA	exaltata	alt. host	Anon., 1957
various insects	Ghana	grandiflora		Kudler, 1970
thrips	Mexico	sp.		Guevara-Calderon, 1958
Thyposidra successaria	India	bispinosa	caterpillars	Chandra & Farooqi, 1979
Amsacta moorei Butl.	India	bispinosa	caterpillars	Chandra & Farooqi, 1979
Tenebrio molitor Linne	China	sp.		Anon., 1979
Agrolis ypsilon Rottemberg	China	sp.		Anon., 1979
Empoasca sp.	Tamil Nadu, India	speciosa		Abraham, 1958

Cyclopelta siccifolia Westwood	Tamil Nadu, India	speciosa		David & Venugopal, 1961
Hyposidra sucessaria Walker	S. India	speciosa	geometrid looper on leaves, flowers	Venugopal, 1958
Semiothisa pervolgata Wlk. = Macaria p.	India	bispinosa	geometrid looper on leaves	Cherian & Pillai, 1938
Pericyma glaucinans	India	bispinosa	noctuid larvae	Venugopal, 1959a
Piezodorus rubrofasciatus	Malaysia	bispinosa		Miller, 1931
Semiothisa pervolgata Wlk.	India	bispinosa	geometrid leaf pest	Venugopal, 1957
Gammodes stolida Fabr.	Tamil Nadu, India	bispinosa, grandiflora	lepidoptera, stem pest	Cherian & Sundaram, 1942
Radopholus similis	C. Am.	sp.	host	Edwards & Wehunt, 1971
Argyroploce rhynchias	Tanganyika	sesban	caterpillars attack branch axes	Ritchie, 1935
Laspeyresia phaulomorpha	Tanganyika	sesban	caterpillars attack branch axes	Ritchie, 1935
Culex spp.	India	grandiflora	mosquitoes found in large numbers in fields	Reuben, 1971
Aphes laburni	Sumatra	grandiflora	aphid	Meer-Mohr, 1935
Mashonania pubescens	Senegal	sesban		Bryant, 1941
Cotton thrips	Sudan	S. sp.	cotton pest, alt. host	Cameron, 1930
Trialeurodes sesbaniae	Australia	tripetii		Corbett, 1936

Alcidodes bubo Fabr.	S. India	grandiflora	weevil, leaves and stems	Subramaniam et al., 1953
Arachnecthra asiatica (Sunbird)	India	grandiflora	birds peck flowers for nectar	Tiwari, 1926
Molpastes intermedium (red-vented bulbul)	India	grandiflora	birds peck flowers for nectar	Tiwari, 1926
Spodoptera littoralis Bois.	UAR	sesban	cotton leaf worm alt. host	Salama et al., 1971
Eurhynchothrips ordinarius	India	grandiflora	in flowers	Ayyar, 1928
Duomitus strix	Indonesia	sp.	wood borer	Kalshoven, 1934
Stegana lateralis V.D. Wulp	Tamil Nadu, India	grandiflora	larvae damage tender stems	CSIR, 1972
Otinotus oncralus Wlk.	India	grandiflora	tree hopper	CSIR, 1972
Prodenia litura F.			tobacco caterpillar, eats leaves	CSIR, 1972

Table 2. Plant diseases affecting *Sesbania* species

Pest	Location	*Sesbania* Species Affected	Comments	Reference
Protomycopsis thirumalacharii	India	grandiflora	fungus causing purple leaf spot	Haware & Pavgi, 1969, 1971, 1972, 1976a, b, c; Pavgi, 1965; Pavgi & Haware, 1970
Sesbania mosaic virus	India	grandiflora		Sreenivasulu & Nayudu, 1982
Photomycopsis ajmeriensis	India	bispinosa	fungus causing galls	Rao, 1972
Pseudo-cercospora sesbaniae	India	grandiflora	grey leaf spot	Kumar & Joshi, 1983
Cercospora sesbaniae	India	bispinosa, sesban		CSIR, 1972
Macrophomina phaseoli (= Sclerotium bataticola)	Texas, USA	exaltata	charcoal rot at stem base	Young, 1949
Colletotrichum capsici	India	grandiflora, speciosa	collar seedling blight	Srinivasan, 1952
Xanthomonas sesbaniae	India	sesban	spots on leaves, leaf rachis, young stems, leaf edges	Patel el al., 1952
Fusarium oxysporum f. sesbaniae	India	sesban	root rot and wilt	Singh, 1956
Collelotrichum coffeanum	Ethiopia	sesban	coffee berry disease, isolated from bark	Gassert, 1978
Sclerotium bataticola	Uganda	sp.	charcoal rot on sweet potato in USA; a hot-weather wilt	Small, 1926

Soybean mosaic virus		exaltata	alt. host	Galvez, 1974
Cherry chlorotic ringspot virus isolated from almond trees	Yugoslavia	exaltata	as test plant, reactions seen	Plese, 1972
<u>Prunus</u> <u>cerasus</u> virus isolates	USA	exaltata	as test plant, reactions seen	Fulton, 1957
groundnut chlorotic spot virus	India	sp.	infected systemically	Haragopal & Nayudu, 1971
Cladosporium	India	cannabina		CSIR, 1972
Uredo sesbaniae	India	sesban	fungi	CSIR, 1972
Daedalea sp.	India	sesban		CSIR, 1972
Diolodia macrostama	India	sesban		CSIR, 1972
Erysiphe polygoni	India	sesban		CSIR, 1972
Rhizoctonia	China	cannabina		Anon, 1979
Corticium solani	Malaysia	aculeata	leaf blight	Turner, 1971
Septobasidium sp	Malaysia	aculeata	on stems	Turner, 1971
Dendryphiella interseminata	Malaysia	specoisa	branch dieback	Singh, 1980
Paecilomyces sp.	Malaysia	specoisa	branch dieback	Singh, 1980
Corticum rolfsii = Sclerotium rolfsii	Malaysia	sp.	wilt	Turner, 1971

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14. EDAPHIC TOLERANCES OF SESBANIA SPECIES.

The abilities of *Sesbania* species to grow in various soil conditions results in an expanded range of adaptability and utility compared to many other types of legumes. In the chapter on soil reclamation using sesbanias, their tolerances of soil salinity and alkalinity were discussed. Here, the tolerances of soil acidity and of soil waterlogging and flooding will be reviewed.

Edaphic tolerances have been investigated to some extent, but relatively less is known about climatic tolerances of these plants. There are no reports of frost tolerance, and the extent of their abilities to grow under cool temperature is uncertain. Best growth is often obtained in summer months, and the rapid growth of annuals such as *S. exaltata* and *S. bispinosa* during extremely hot summer weather has been observed. Little is known about drought tolerance. It appears that abundant water is favorable to early growth, but there is evidence that many species can continue to grow well under subsequent, increasingly dry conditions.

Tolerance to acid soil conditions.

Reports on the tolerance of *Sesbania* species to acid soil conditions are few and for the most part insubstantial. In India, *S. bispinosa* is widely known for its tolerance of soil alkalinity, but it is also said to be tolerant of soil acidity, a reputation which may be due to repetition of an early report that the crop was grown as a green manure on acidic tea-growing soils in Assam (e.g. Mirchandani & Kahn, 1952; Patel, 1966). Reports from Viet Nam that S. sesban is grown successfully on acid sulfate soils have not been verified by scientific literature available to us. Those soils have pH around 6.5 when flooded, decreasing to about pH 4 when dry. Tran Fhouc Duong of Cantho Agricultural College, Viet Nam, illustrated a lecture given at the University of Hawaii in 1983 with a photograph of a Sesbania species growing in soil crusted with aluminum salts, and stated that sesbania was generally sown at the end of the monsoon season.

S. sesban (as S. aegyptiaca) was included among 33 legumes tested for N production in pot experiments with a "red" soil in Hawaii (Thompson, 1917); soil pH was not given, but the soil, probably an Oxisol, was stated to be "apparently acid...low in phosphate and lime and of poor texture." Sesban and the velvet bean (Mucuna sp) were distinguished as potentially useful green manure crops on such soil, especially if lime could be applied.

Nair et al. (1957) reported experiments with S. speciosa grown on laterite soils (pH 5.4) near Coimbatore, India, to determine growth response to lime (1680 kg/ha), P (34 kg/ha superphosphate) and farmyard manure (5600 kg/ha). Maximum yield of 40.3 Mg/ha fresh material for the 60-day crop was obtained with all three amendments, but the yield of the control was 21.4 Mg/ha. Lime seemed to be the most valuable input for increasing crop growth and nodulation, although a small initial increase in soil reaction due to lime was not significant after growing the crop. Adding lime increased N yield by 28 kg from 87 kg/ha; adding all three amendments produced 136 kg/ha N.

Acid soils are frequently low in available P, and this may be as important a factor limiting legume growth as low levels of calcium, hydrogen ion concentration, or toxic levels of soil minerals such as Al and Mn. Experimental work in India indicates that the common green manure sesbania, S. bispinosa or S. cannabina, locally known as dhaincha, is quite efficient in P uptake. In pot experiments, Khare et al. (1973) found dhaincha and Glycine max to be more efficient than Crotalaria juncea, Vigna aureus, or V. unguiculata in utilizing soil P, and dhaincha was also superior in taking up P from added fertilizer. Subbiah & Manikar (1964) found that dhaincha was more efficient than C. juncea or Cyamopsis tetragonoloba in extracting P added to the "subsoil" (below 20 cm) layer of pots 30 cm deep. Singh et al. (1968) grew legumes for 50 days in pots containing 13.6 kg soil, with and without superphosphate at 56 kg/ha P2O5. All species tested showed yield increases in response to added P but while sesbanias showed much less increase in total dry matter (average 33% increase due to added P) than C. juncea (433%), V. unguiculata (155%), or C. tetragonoloba (240%), sesbania yields were considerably higher: 2 of 3 sesbania entries had higher yields and total plant N without added P than the other legumes had with P. Singh (1972) obtained a small (<30%) yield increase to the first increment of added phosphate (33 kg/ha) in dhaincha grown in field experiments, but increases to higher rates were negligible.

Another demonstration of efficiency of P uptake by S.

bispinosa was provided by Mahajan and Khanna (1968), who grew the crop for 85 days with varying P fertilization. Their data, shown in Table 1, indicates that increasing P levels did not increase yields beyond the first increment of P applied, but % P in plant tissue increased with increasing P (R=0.97) as did total P recovered in the crop. In comparison, percent recovery of applied P by a cowpea crop averaged 14%.

In Hawaii, legumes including *S. grandiflora* and *S. cannabina* were grown across a pH gradient established by liming a manganiferous Oxisol (Yost et al., 1981, 1985). The variety of cannabina used (USDA PI 180050) appeared quite sensitive to low pH and the associated high levels of available soil Mn, as may be seen in Table 2. This variety has been found to be dissimilar from other species accessions received as *S. cannabina* (or the similar *S. bispinosa*) which were subsequently observed in other experiments in Hawaii (Evans, personal observation), and thus these results may not be applicable to all *S. cannabina* materials. Although amounts of nitrogen accumulated in *S. grandiflora* were low compared to the fast-growing annual crops, it showed a tolerance to low pH comparable to that displayed by *Crotalaria juncea*.

Table 1. Yield and P recovery by a phosphate-fertilized *S. bispinosa* crop (data of Mahajan & Khanna, 1968).

P205 Added	Dry Matter Yield	%P	kg P205 Recovered	% Recovery
0	5.50	0.245	13.5	--
45	6.30	0.547	34.5	47
90	6.24	0.756	47.2	37
135	6.07	1.311	79.6	49

Table 2. Nitrogen content (kg/ha) of legumes grown 10 weeks in relation to soil pH as modified by lime application on a manganiferous Oxisol (from Yost et al., 1985). Values in parenthesis are percentages of N content at pH 6.9.

Species	soil pH 4.7	5.3	5.8	6.5	6.9
Sesbania cannabina	1.6 (3)	7.5 (14)	22.5 (44)	29.6 (57)	51.6 (100)
Sesbania grandiflora	3.7 (26)	7.0 (49)	10.8 (76)	13.3 (94)	14.2 (100)
Crotalaria juncea	21.0 (20)	44.0 (42)	72.0 (68)	96.0 (90)	106.0 (100)
Zea maize	22.2 (70)	26.9 (84)	26.6 (83)	26.3 (82)	31.9 (100)

Tolerance to soil waterlogging and flooding.

The extensive use of *Sesbania* species in Asian cropping patterns based on lowland rice has been described elsewhere in this report, including their cultivation as intercrops simultaneously with flooded rice crops in China. Also noted have been the uses of sesbanias in paddy margins to product bunds from wave erosion, and as living screens across shallow waterways to prevent incursions by floating aquatic weeds. Green manure species selection trials have singled out *Sesbania* species for their abilities to withstand flooding, as reported by Allen (1956) for Malaysia, the International Rice Research Institute in the Philippines (IRRI 1964), and India's Central Rice Research Institute (CRRI, 1962, 1963, 1964). Jen et al. (1965) in China noted that sesbania survived flooding for a period of 15-20 days, at water levels from 5-30 cm deep. In N. America, *S. exaltata*'s ability to grow as a green manure crop while flooding eliminated many weed species has been noted (Pieters, 1927), and sesbanias of the subgenera Glottidium and Daubentonia (*S. vesicaria* and *S. drummondii*, respectively) are included among wetland plants of the southwestern USA (Correll & Correll, 1975). The natural habitat preference of many sesbanias is for stream banks, flood plains, swamps, lake margins, and other low-lying, moist or seasonally moist soil environments (Gillett, 1963).

The tolerance of sesbanias to flooding is generally recognized as developing after the seedling stage. While green manure crops of *S. bispinosa* may be sown in a few centimeters of standing water to aid germination (Abrol & Bhumbla, 1971), the seedlings appear to need several weeks of non-flooded conditions before they can readily withstand flooding; this has apparently not been studied in detail, although farmers using the crops may be acquainted with the limits of the tolerance for the species they use. In North America, the weed S. exaltata was shown to emerge and grow well when seeded 1.3, 2.5, and 5.1 cm deep in a silt loam soil held at field capacity (24% water) or saturation (34%), but it did not grow when the soil was submerged (Smith & Fox, 1973).

The basis of flooding tolerance in Sesbania is the development of aerenchyma, a spongy tissue having enlarged cells with large intercellular spaces. General reviews on plants growing in watery environments, such as that of Scullthorpe (1967), include aerenchyma development as one of several ways in which plants may avoid anoxia in the root zone. In Sesbania, this tissue arises from a phellogen tissue located just outside the endodermis. The morphology of this development occurring on stems and roots has been described by Scott and Wagner (1888), Metcalfe (1931), and d'Alemeida (1946). The latter author pointed out the definite pattern of cellular development, with concentric rings of rounded cells girthing layers of scattered, radially elongated cells, resulting in the intercellular spaces illustrated in Figure 1. There is no research available on the biochemical and physiological nature of this response in Sesbania, so there is no reason to believe that these plants tolerate the absence of oxygen; rather, aerenchyma development is primarily an avoidance mechanism to partially prevent anoxia and perhaps to ameliorate some of the consequences of this condition. Such consequences were detailed in recent reviews by Cannell and Jackson (1981) and Krizek (1982).

Swelling of the flooded basal stem is visually evident within 12-24 hours of flooding. The epidermis splits from the soil level to above the water level, and a white tissue may be seen beneath it, sparkling with tiny reflective air bubbles. The swelling stem acquires a fissured, buttressed appearance, 3-4 or more times the original stem diameter at soil level, narrowing to normal diameter at the intact epidermis a few cm above water level. Subsequently, within 1-2 weeks, submerged water roots sheathed in aerenchyma arise from the flooded stem section, growing out through the aerenchyma, and roots near the soil surface may arch above it, bouyed by aerenchyma. Nodules may be seen nestled in the airy tissue at the base of the stem or scattered along water roots. The botanists describing this phenomena have discussed the function of the arenchyma in providing oxygen for root respiration, but they failed to note nodulation, or that the intercellular spaces also serve to transport gaseous nitrogen to sites of N-fixation.

Development of aerenchyma is not unique to Sesbania within the Leguminos ae. Neptunia contains floating plants with aerenchyma; Metcalfe (1931) discussed both Sesbania and Neptunia. Trials at IRRI (1963) also found Macroptilium lathyroides suitable for waterlogged conditions. Aeschynomene contains species of agronomic potential which survive flooding (Kretschmer & Bullock, 1980). Mimosa pigra and Lotus pedunculatus also develop aerenchyma (Sculthorpe, 1967). Glycine max shows aerenchyma development, and some cultivars have been found to grow better under high water table culture (3 or 15 cm from the soil surface) than under freely drained conditions (Hunter et al., 1980). Vicia faba also was shown to have better growth and nodule development in saturated media than under drained conditions (Gallacher & Sprent, 1978). Few of these genera show as dramatic a morphological response to flooding as does Sesbania, although it should be noted that the extent of these developments varies among Sesbania species.

Screening for flooding tolerance in legumes has been done for temperate forage legumes flooded 5-20 days at about 50 days after planting (DAP) (Heinrichs, 1970). Brolmann (1978) kept 158 Stylosanthes accessions flooded at the soil surface level from 28 DAP and recorded survival during the subsequent 4-month period. Miller and Williams (1981) flooded 41 tropical legumes (but no Sesbania species) to 7 cm above soil level at about 14 DAP, and some survived 6 months of this treatment.

Research on flooding tolerance in Sesbania is rare. IRRI (1964) reported briefly on a comparison between Sesbania species grown under flooded and drained conditions. Agriculturists in Guangdong, China reported an experiment with S. cannabina comparing flooded and drained conditions (Anonymous, 1975). Seedlings established in a soil lacking infective rhizobia were transplanted to inoculated, fertilized (but without N) sand culture in pots which were then either flooded to 3 cm of standing water or were maintained below field capacity; the flooded treatment was grown with and without added N. One month after transplanting, plants were harvested and the N in plants and media was measured, as given in Table 1. The timing of events in the experiment was similar to the practice of raising sesbania in nurseries and bare-root transplanting seedlings as an intercrop in flooded rice fields. It is possible that the development of aerenchyma in the flooded treatment and, especially, the addition of N to the N-poor sand media, conferred advantage compared to the non-flooded treatment, allowing more rapid recovery from transplant shock and thus an earlier and greater supply of photosynthate to the nodules. Considering the difficulties in comparing plant growth in such different root environments, particularly in regard to nutrient uptake, the workers at Guangdong hesitated to conclude that increased growth was a result of greater N-fixation and not an artifact of their proceedures. It was clear, however, that flooding did not severely inhibit plant growth and N-fixation.

The extent to which tolerance of flooding is typical of species of Sesbania was assessed in an experiment in Hawaii (Evans and S. Somphone, unpublished data). Twenty-two Sesbania accessions were grown in pots for 5 weeks, after which they were either flooded by sealing the pots and maintaining water level at 5 cm above soil level, or kept in saturated condition by setting the pots in shallow, water-filled pans. Plants were thinned at the imposition of treatments and the remaining plants harvested 18 days later. The soil was a Vertic Haplustoll (Waialua series), a moderately heavy clay soil dominated by smectite clay minerals having shrink-swell potential; therefore, the non-flooded and flooded treatments may not have represented root and nutrient flow relationships as different as was the case with the sand used in the Guangdong study (Anon., 1965).

The species grown included the perennials *S. arborea* (AR4), *S. grandiflora* (GL5), and two varieties of *S. sesban* (SB1, SB10), and the annuals *S. emerus* (XP), *S. macrantha* (MN1), *S. exasperata* (EX3), *S. punicea* (subgenus Daubentonia) (DF2), *S. vesicaria* (subgenus Glottidium) (VC1), *S. erubescens* (EB1), *S. pachycarpa* (PC1), *S. exaltata* (MA4), *S. rostrata* (RS1), *S. speciosa* (SP1), *S. tetraptera* (TF1), *S. cochinchinensis* (CH1), and several accessions of the *S. cannabina*-*S. bispinosa* type (BA5, CB1, CB5, SC1, XE3). Seven accessions were grown with 3 replications, and the remaining 14 were unreplicated.

The results of this experiment are depicted in Figure 1, which compares plant dry weights under the different treatments. Entries clustered along the diagonal axis grew as well under both treatments. There was a tendency, particularly for the higher-yielding entries, to be moderately more productive under non-flooded conditions. Some of the lower-yielding entries were perennials (MN1, AR4, SB10, GL5, SB1, EB1), while most higher-yielding entries were fast-growing annuals.

Table 1. Nitrogen budget of *Sesbania cannabina* transplants grown under flooded and drained conditions (from data of Anon., 1975).

Treatment	Plant Dry Wt.	Plant N Content	N Added	N Fixed*
	g/pot	mg/pot	mg/pot	mg/pot
Drained	12.1	449	0	404
Flooded	17.1	612	0	572
Flooded +N	32.5	1144	345	759

* N content of transplants (40 mg/pot) deducted; discrepancies in budget are due to N remaining in media after harvest of plants, and to rounding.

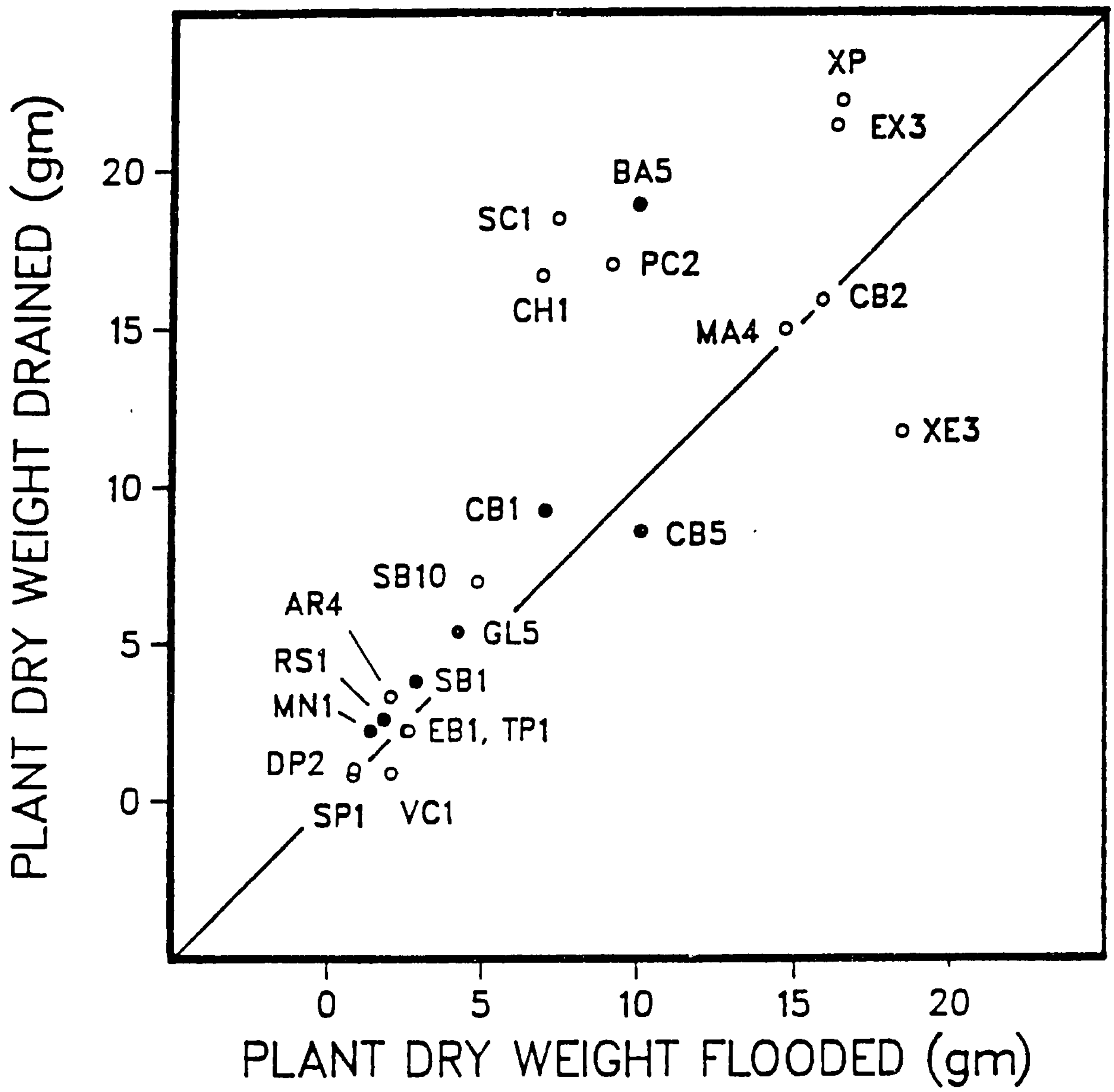

Figure 1. Yield of <u>Sesbania</u> accessions subjected to flooding (5 cm above soil level) or high water table (20 cm below soil level) conditions for 18 days, 35 days after sowing. Solid circles were 3-replicate entries; open circles were unreplicated (Evans and S. Somphone, unpublished data).

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PRODUCTIVITY OF *SESBANIA* SPECIES

1. ANNUAL SPECIES WITH AND WITHOUT CUTTING MANAGEMENT.

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Abstract.

Annual *Sesbania* species are underexploited and underutilized legume sources of pulp fiber, animal feed, and green manure. Of 35 accessions tested for yield, 25 high-yielding varieties (HYVs) produced 8-17 Mg/ha dry matter containing 150-245 kg/ha N when sown at 125,000 plants/ha and harvested 98 days after planting (DAP). Most HYVs were similar to *S. bispinosa* or the nearly synonymous *S. cannabina*, grown as green manures in Asian lowland rice systems. When harvested twice with cuts 50 cm above ground level at 49 and 84 DAP, HYV dry matter production was slightly depressed but N production was enhanced compared to the 98-day growth period. Variations in flowering and growth duration in relation to season were discussed.

Additional key words: *Sesbania speciosa*, *Sesbania rostrata*, *Sesbania emerus*, *Sesbania pachycarpa*, *Sesbania macrantha*, *Sesbania punicea*, *Sesbania vesicaria*, *Sesbania tetraptera*, *Sesbania microphylla*.

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Introduction

Fast-growing legumes are potential low-cost nitrogen sources for cropping systems and are also sources of biomass for feed, fuel, or fiber. *Sesbania* contains both annual and perennial species which may be appropriate for these purposes in the tropics and subtropics. We conducted yield experiments in Hawaii to compare productivity of a number of sesbanias. Yields of perennial species including *S. sesban* and *S. grandiflora* harvested regularly for fodder are the subject of another report (Evans and Rotar, 1985); this report is of yields of 35 annual *Sesbania* accessions grown for approximately 3 months, including a subset subjected to one cut during that period.

Most information on yields of annual sesbanias is from green manuring studies which frequently neglected to present comprehensive agronomic data. Of those summarized in Table 1, few gave values for either dry matter yield or nitrogen content, and none mentioned plant populations. The rapid growth of some sesbanias is illustrated by Singh and Sinha (1962) who grew sesbania as an intercrop with maize: when the legume and maize seeds were mixed and sown in the same row, the legume smothered the maize. While occasionally grown as intercrops and as border crops, annual sesbanias are more often grown in solid stands as green manures preceeding cereal crops, especially rice, and are valued for their tolerance of soil salinity, heavy soils, and waterlogged or flooded soils.

Except in certain problem soils such as the saline-alkali soils of India where green manures are important for reclamation and maintenance of favorable soil conditions, the practice of green manuring is declining because farmers prefer to grow a harvestable crop. New management alternatives for fast-growing legumes may help to overcome farmers' reluctance to include these crops in their systems. Multiple uses of green manure legumes enhance their appeal for use in cropping patterns, and the partitioning of green manure crop yields for fodder, while the remainder is incorporated, is one example. Sesbania species may also be substituted for non-legume pulp fiber crops, or the stalks may be burned for fuel, or their seed may be harvested for endosperm gum extraction, while the crop residues benefit the cropping sequence.

Materials and methods.

The experimental site was field J-2 of the University of Hawaii Waimanalo Experiment Station on coastal windward Oahu, Hawaii, latitude 21′20", elevation 25 m. The site is located on a fan of alluvium and is somewhat stony with moderate drainage. The soil is a Vertic Haplustoll (Waialua series), pH 6.2, of low to medium fertility. The field had been under guava with an understory of grasses and weeds and had no recent history of fertilization at the time it was cleared for this experiment. A basal dressing of triple superphosphate was applied at 100 kg/ha P. Irrigation was by overhead sprinkler.

Seeds were scarified by soaking for 15-30 minutes, depending on the accession, in concentrated sulfuric acid and then washing in running water for 10 minutes. A mixture of <u>Rhizobium</u> cultures isolated from <u>Sesbania</u> species and carried on peat was applied as inoculum to the scarified seeds coated with gum arabic solution as a sticker. Seed was then sown at a depth of about 2.5 cm in hills 20 x 40 cm apart at a rate of 3 seeds/hill and the field was then irrigated on June 8, 1983. Seedlings were thinned to 1 plant/hill 18 days after sowing to obtain a population of 125,000 stems/ha.

Accessions grown are listed in Table 2. As indicated, there is uncertainty about correct species identification in many cases. Taxonomic treatments exist for Australia (Burbidge, 1965) and for Africa (Gillett, 1963), but regretably, not for Asia. The majority of the entries marked "?" belong to a group comprised of <u>S. bispinosa</u>, <u>S. cannabina</u>, and <u>S. sericea</u>, which are closely related plants, somewhat similar in appearance but given species status on the basis of taxonomic considerations such as flower size, leaflet vestiture, and presence of prickles on leaf rachis and stem (Gillett, 1963). Although some accessions marked "?" may be distinct species other than those three (e.g. CH1, XE3, XE7, XE8, MA4, and CB1), in the following discussion we refer to all of these questionable entries as "the cannabina group."

Two separate experiments were conducted. In Experiment 1, 35 accessions (Table 2) were sown in a completely randomized design with 3 replicate plots per accession. Plots consisted of 4 rows 4 m long and 40 cm apart with the inner 2 m of the central 2 rows serving as harvest area; net harvested plot size was thus 0.8 x 2 m containing 20 plants. Harvest was 98 days after planting. Plants were cut at ground level. Two plants were taken from each harvest area for moisture content and chemical analysis. Leaves and branches less than 3 mm in diameter were separated from the main stems and considered as the leaf fraction. Non-harvested row ends were left standing for seed increase, and wood samples for density determinations were taken from these plants about 6 months after sowing. Samples, taken from the gravitational midpoint of stems trimmed of side branches, were weighed and soaked in water for 4 hours before measuring volume by submersion, and then were dried in a crop drying oven at 50 C for three days followed by drying at 103 C until constant, bone dry weight was achieved. Specific gravity was expressed as bone dry weight in kilograms per cubic meter. During the period between harvest for yield data and sampling for stem density there was no irrigation, most accessions were in reproductive phases, and substantial further biomass production was not apparent.

Experiment 2, in which 10 of the 35 entries from the growth trial plus one accession of the perennial S. sesban were grown, was sown simultaneously with Experiment 1. In addition, 2 of the entries (MA4 and CB5) were planted at double density (i.e. 10 cm rather than 20 cm apart within rows). Plots consisted of 3 rows 4 m long in a randomized complete block design; harvest area was the inner 2 m of all 3 rows, resulting in a net harvested plot size of 1.2 x 2 m containing 30 plants. Plants were cut at 50 cm above ground level 7 weeks after planting, and the regrowth was cut again at the same height 5 weeks later. Leaf and stem fractions were separated as in Experiment 1.

Plant samples for moisture determination were dried in a crop drying oven at 50 C. Chemical composition of plant tissues was by X-ray flourescence spectroscopy with an Applied Research Laboratories spectrophotometer model 72 000. Total N in plant tissues was determined by a modification of the Berthelot method described by Suehisa (1980).

Results and discussion.

Experiment 1. Relationships between dry matter yield and nitrogen content of 35 Sesbania accessions are illustrated in Figure 1, while yield data are given in Table 3. Although there is no break in the continuum of dry matter yield values in Figure 1, values for N content separate the entries into 2 subgroups which we will designate the high-yielding varieties (HYVs) and the low-yielding varieties (LYVs) in the following discussion. In general, the HYV entries belong to the morphologically similar "cannabina group" of closely related plants, while the LYV group are species with more prominent distinctions. The mean plant height for all entries was 3.3 m.

High yielding varieties had an N content of more than 150 kg/ha N in their tops. Two-thirds of the accessions tested are in this group; their above-ground N content averaged 181 kg/ha N with a range of 149-245 kg/ha N. Included in this group are S. exasperata, S. emerus, S. concolor, and all accessions in the cannabina group. Dry matter yields ranged between 8 and 17 Mg/ha with one-third of the dry matter and three-quarters of the nitrogen in the leafy fraction. Mean fresh yield of the HYV's was 42 Mg/ha, with an average fresh weight accumulation of 428 kg/ha/day compared to an average of 380 kg/ha/day for S. bispinosa as reported in the literature (Table 1).

The large amounts of woody stems produced in the growth period of this experiment would be difficult to incorporate as a green manure crop without tractor-drawn disc plows, although such a green manure crop would make a contribution to soil organic matter by providing a large quantity of slowly decomposing high C:N ratio material. It would also provide a large input of readily decomposable leaf N, the value of which might be offset by difficulties of seedbed preparation due to the accompanying stem material. As a pulpwood or fuelwood crop, after harvest of the stems a substantial amount of leaf material could be available for fodder, or left in the field, or carried elsewhere for green leaf manure. The stems of the 3-month crop would also be useful as trellising poles for climbing crops. As in situ green manure crops for non- or lightly-mechanized farms, a shorter growth period would probably be more appropriate for these species.

The 14-week growth period of this experiment was chosen to sample the majority of accessions at the peak of their vegetative productivity, and not to represent ideal conditions either for a short-term green manure crop or a longer-term pulp fiber crop. More explicit experiments are needed to select sesbanias for either purpose.

Sesbania species have seen extensive use as green manures, but research to explore their potential as pulp fiber sources is very limited. They are promising for this purpose, however, growing rapidly without N fertilizer, being easily stored after harvest without deterioration, and producing woody stems with reported specific gravity of 300 kg/m^3 or more yielding a fiber similar to that of birch (L. Markila, personal communication). Under our conditions, stem midsection specific gravities were somewhat less (Table 3), and there was a fair amount of pith in the stems. Hollow and pith-centered stems would be amenable to decomposition in the soil, but dense, woody stems are preferable for pulp. Research on the conditions dictating variability in stem morphology is necessary to maximize pulp fiber yields of *Sesbania* species.

It is also appropriate to beware of erronious conclusions based on limited germplasm collections. A variety of institutional sources does not ensure genetic variability, because the same materials are frequently passed around among institutions. Accessions collected as green manure crops have had different selection criteria than would be appropriate for pulp fiber crops. There are no extensive collections of *Sesbania* species made from natural populations, and existing collections have seldom adequately characterized the collection site climate and soil type. Proper collection and subsequent screening to select materials for different purposes and different soil-climate environments is imperative for a rational development of potentially valuable germplasm resources such as *Sesbania*.

Of the low-yielding varieties, the lowest yielding entries were *S. punicea* and *S. vesicaria*. Both are temperate zone plants belonging to the subgenera Daubentonia and Glottidium, and their placement in *Sesbania* is a matter of continuing controversy. *S. tetraptera*, distinguished by its 4-winged pods, belongs to another subgenus distinct from the subgenus Sesbania to which most of the other entries belong. The LYV group also contains two species which are not clearly annuals: *S. pachycarpa* which in Hawaii may continue to grow, but without vigor, after its first reproductive period, and *S. macrantha*, some varieties of which live for several years. The other LYVs were *S. microphylla*, a slender plant with the smallest leaflets in the genus, and *S. speciosa*, which is often border-planted as a green leaf manure crop in South India; as an in situ green manure, it is known to be slower than *S. bispinosa*, taking 3-5 months rather than 2-3 months to produce a good green manure stand.

S. speciosa was probably not symbiotic with *Rhizobium* in this experiment, since we have not been able to effectively inoculate it with *Rhizobium* isolates from other *Sesbania* species, including those comprising the inoculant used in this experiment. Reports from India suggest that high yields may be obtained with this species, presumably when nodulated. We attribute the low yield and N content of *S. speciosa* in our experiment to its lack of an effective N-fixing symbiont.

The same limitation applied to *S. rostrata* (see Fig. 1). This species was reported as a prodigious nitrogen-fixer (Rinaudo et al., 1983). Its unusual stem nodules are said to fix atmospheric N regardless of available N in the rooting media (Dreyfus and Dommergues, 1980). This stem nodulation is apparently ephemeral, dependent on environmental conditions, and requires unique, specialized *Rhizobium* strains. Our attempts to effectively nodulate roots or stems of *S. rostrata* with isolates effective on other sesbanias failed. In this yield trial, there were no stem nodules. *S. rostrata* had a high dry matter yield, similar to the HYV's and significantly higher than *S. speciosa*, but a relatively low N content, since its roots were apparently not effectively nodulated. The low yielding varieties, in summary, lacked an effective symbiosis, high biomass yield potential, or both, and they had N contents of less than 100 kg/ha.

Experiment 2. Figure 2 illustrates the dry matter yields of two successive harvests of ten *Sesbania* accessions cut at 50 cm above ground level. These entries are ranked, from left to right, by total dry matter yield for the combined two harvests. The perennial *S. sesban*, not shown in Figure 2, was similar in yield to CB5 at both cuts, thus exhibiting quite rapid early growth for a perennial (cf Evans and Rotar, 1985). Dry matter accumulation rates during the 5-week regrowth period were comparable to those in the uninterrupted, 14-week growth period of Experiment 1, and these rates were 50-200% higher in the regrowth period than in their establishment period.

Figure 3 compares the combined dry matter yields from 2 cuts in Experiment 2 (left bars) with the yields in Experiment 1 (right bars). Entries with comparable yields when grown for 14 weeks behaved differently when subjected to an intermediate cutting. Some entries (SC2, XE3, CB5, and MN1) had conspicuously greater dry matter yields during their regrowth period after the first harvest than during their establishment period, and they also had higher proportions of leaf to stem in their dry matter at the first cut. Such differences in growth rates may be of use in selecting varieties for intercalating, as relay-sown intercrops for example, in cropping patterns.

Nitrogen yields for the growth intervals in both experiments are compared in Figure 4. While the combined dry matter yields of two cuts in Experiment 2 were generally less than the corresponding yields in the uninterrupted growth period of Experiment 1, for almost all entries the combined N contents of the two cuts were equal to or greater than the N contents in Experiment 1. Accessions containing approximately 100 kg/ha N at 7 weeks after sowing would be most desirable as short-term green manure crops. Cutting these plants as we did not only provided an intermediate harvest for fodder or green leaf manure but in most cases stimulated production of N-rich leafy material instead of stem material to the extent that an additional 100 kg/ha N could be harvested 5 weeks later.

The two entries in Experiment 2 which were grown at two plant populations are compared in Figure 5. These accessions represent extremes in flowering habit among the annual sesbanias: MA4 flowers precociously throughout the year in Hawaii, while CB5 seems to require daylengths which are short enough only in winter (November to February) in Hawaii. During this experiment, MA4 flowered before the first cut, while CB5 never flowered. This interaction of flowering physiology and plant population greatly inhibited regrowth of MA4 after the first cut.

Little difference in yield of S. exaltata grown for green manure in California was obtained by increasing sowing rates from 22.4 to 44.8 kg/ha (Anon., 1957). From the performance of our two entries, it is not clear that sowing to achieve very high plant populations is of advantage in increasing short-term productivity of sesbanias. With the relatively slower-growing CB5, there was a difference in N content at the first cut: an additional 23 kg/ha N due to doubling the population to 250,000 plants/ha. It appears, however that the population of 125,000 plants/ha chosen for these experiments was an appropriate population for these plants. This is corroborated by comparing the results of the two experiments. This plant spacing allowed for a canopy adequate to support high biomass yields in Experiment 1; imposing a cutting regime intended to stimulate leaf production in Experiment 2 did not succeed in increasing leaf fraction yields, although cutting did produce regrowth with a higher N percentage, resulting in greater N content.

Some of the green manuring data on sesbanias summarized by

Panse et al. (1965) for India (Table 1) indicated that yields varied with sowing times: in one species comparison, sesbania green manure crops were grown both for main season (mid-year) and late season rice crops. Table 1 gives only the data for the main season crop (those grown for 84 days); for the late season crop, yields for S. bispinosa, S. sericea, S. macrocarpa, and S. speciosa were 30, 36, 42 and 59%, respectively, of the main season crop. In another comparison, S. bispinosa was sown a month apart, in May or in June. The latter sowing yielded 10% more when grown 98 days on a sandy loam soil, and 52% more when grown 102 days on a "black cotton" soil. Differences between the May and June sowings may be related to the monsoon and its influence on available water and solar radiation, and differences between sowings for the main and late season rice crops may also have been related to flowering in response to decreasing daylength.

We have previously observed variation in days to flowering among the annual sesbania accessions used in this study when planted in early August in Hawaii (Evans, 1983); most of them began to flower within 8 to 10 weeks of sowing, although a few including S. macrantha MN1, S. cannabina CB5, and S. speciosa SP1 did not flower until 17 weeks from sowing. In the present experiment, a number of accessions which according to our previous observations were known to be physiologically capable of flowering within a 14-week period did not do so. These were S. microphylla, S. rostrata, S. pachycarpa, S. emerus, S. exasperata, and the cannabina group accesions CH1, CB2, CB3, CB6, and BA3. Accessions

MN1, CB5, and SP1 also did not flower. *S. punicea* has not been observed to flower in any of our plantings. This suggests that in *Sesbania* daylength is a factor in flowering and that there is variation among and perhaps within species.

Allied to this flowering response is a difference in determinateness among species; by determinate, we mean that the reproductive phase is soon followed by senescence. Some sesbanias considered to be annuals are very determinate in Hawaii, while others continue to grow after flowering and setting seed. An example of the determinate type is the accession MA4, which flowers within 6-8 weeks of sowing at all times of year in Hawaii. Accession CB1, very similar to MA4, and accession BA7 are two others. In Experiment 1, CB1 had mature seed at harvest 3 months after sowing. These 3 accessions have flowering habits that would be expected in temperate zone species, such as the North American *S. exaltata* which MA4 may be. They had similar dry matter contents and N yields, and their values were clustered for most characters measured (see Fig. 1). For total N content they were high-yielding varieties, but for dry matter yield they were intermediate between the high- and the low-yielding groups, significantly lower-yielding than the highest of the HYVs. They had more dry matter in the leafy fraction than in their stems, and the proportion of leaf N to stem N was very high (Table 3). Had they been harvested earlier, their growth rates would have been relatively higher, since they apparently reached peak biomass accumulation earlier than the others. These 3 accessions are

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therefore candidates for short-term green manure crops, but their precocious seeding habit deserves cautionary consideration where there is a risk that timely incorporation may not be possible.

We conducted these yield trials with *Sesbania* species during summer, when good yields may be expected. Additional information on yield variation resulting from differential growth performance due to season would be useful in determining limits to their feasible inclusions in cropping patterns.

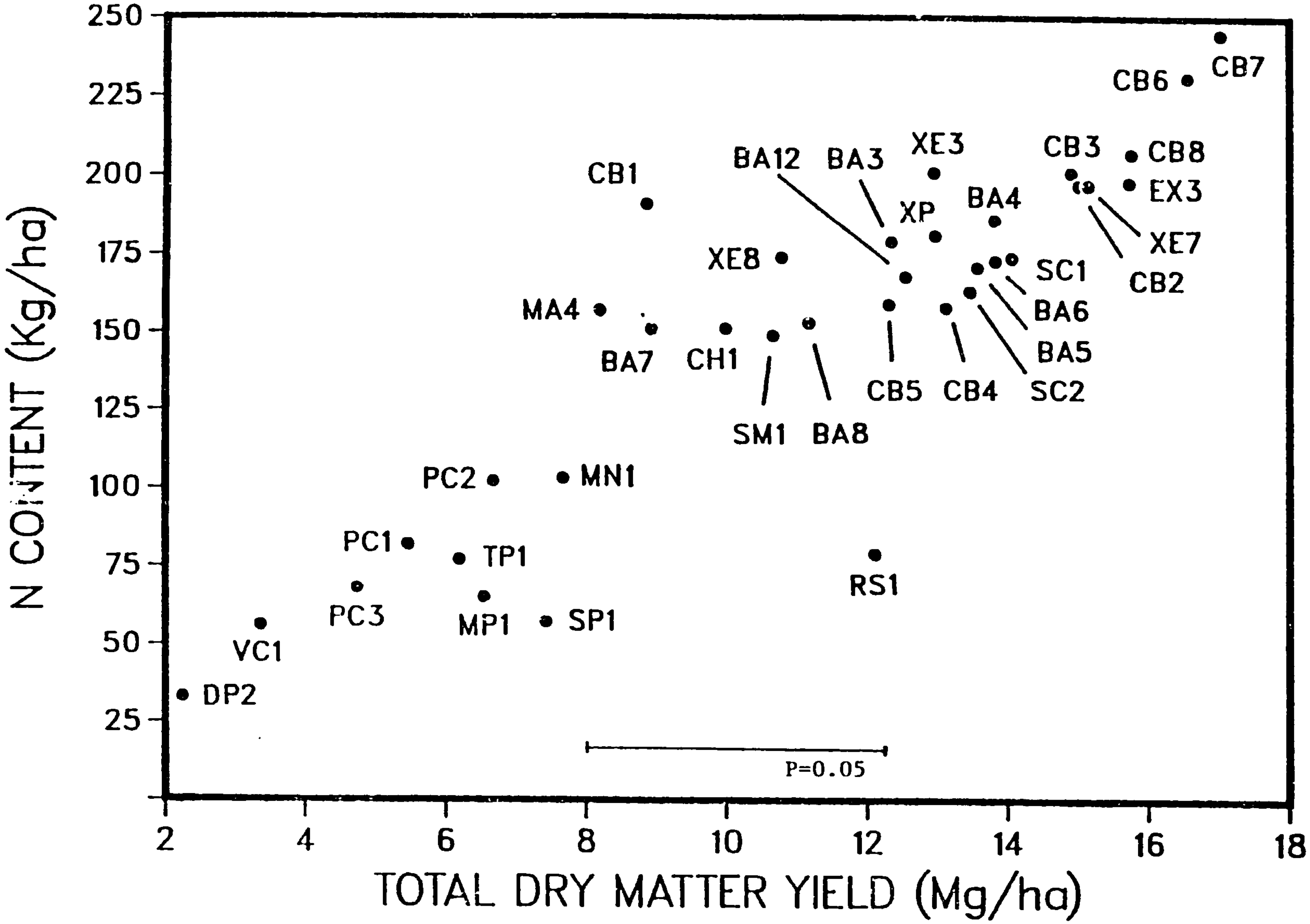

Figure 1. Plot of dry matter yield v.s. nitrogen content for 35 *Sesbania* accessions grown for 94 days (see Table 2 for key to species accession codes).

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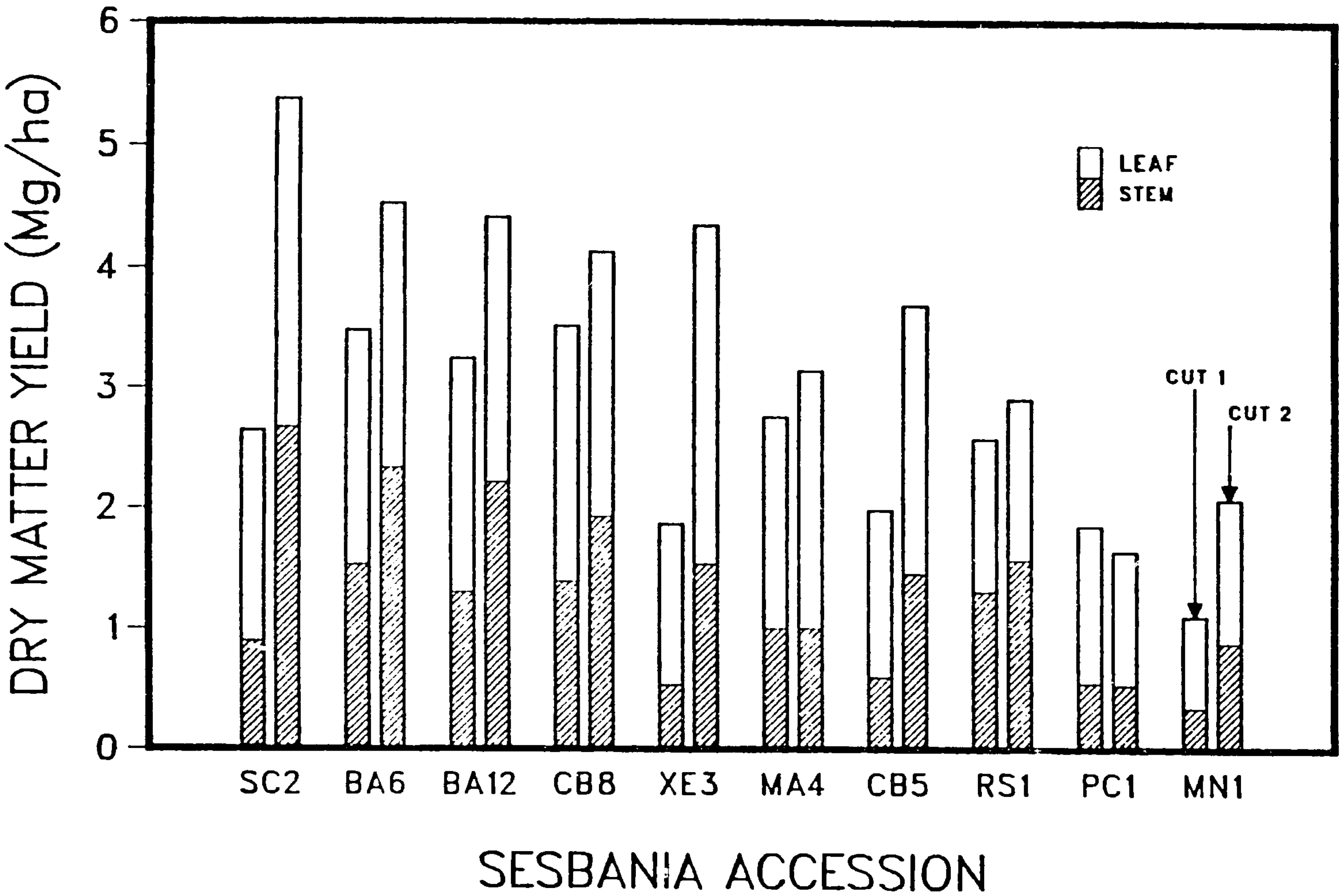

Figure 2. Dry matter yields of Sesbania accessions cut twice (cuts were 49 and 84 days after planting).

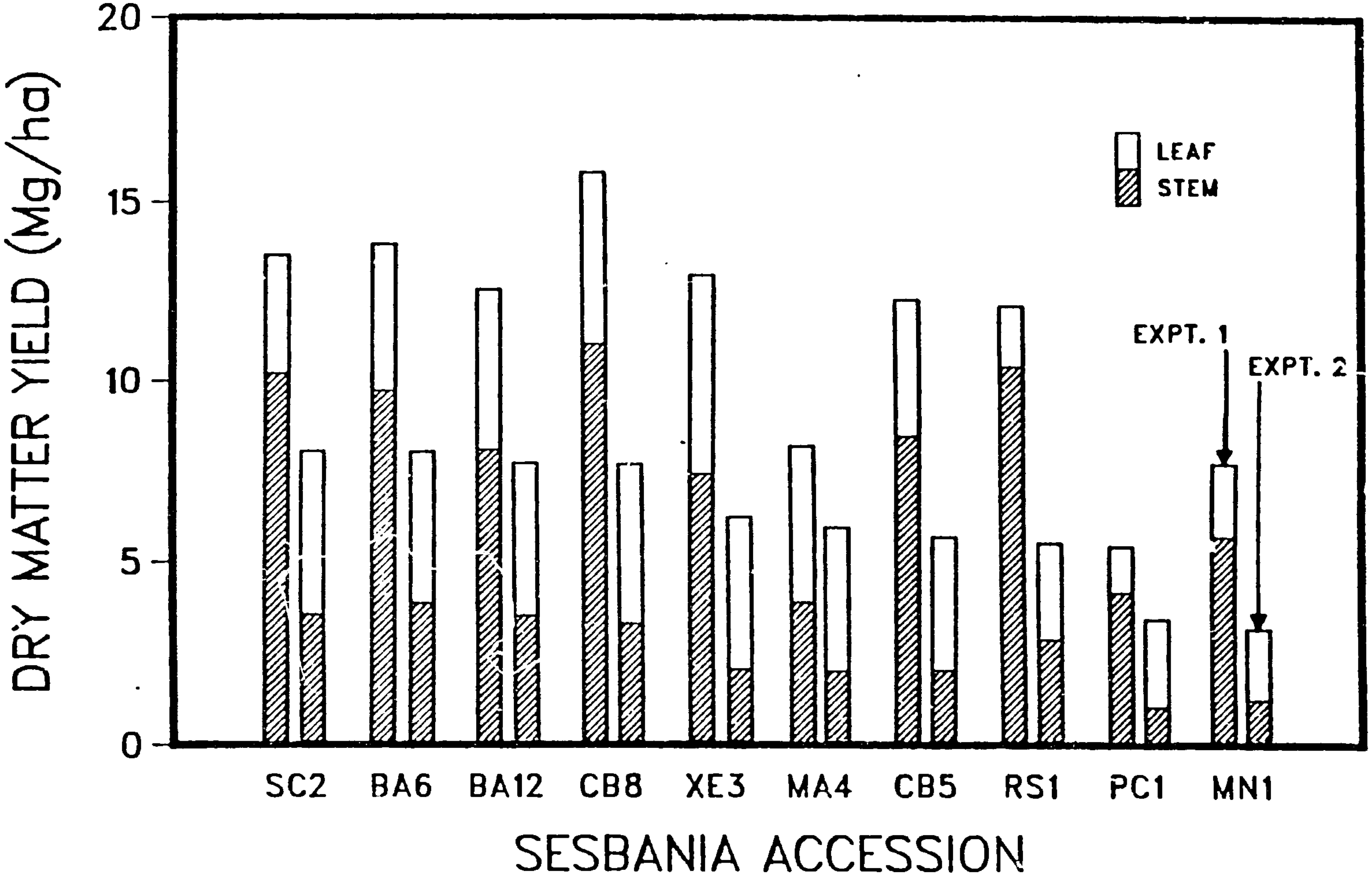

Figure 3. Dry matter yields of *Sesbania* accessions in two concurrent experiments. Experiment 1 (left bars) was harvested 94 days after planting. Experiment 2 (right bars) was harvested twice, at 49 and 84 days after planting.

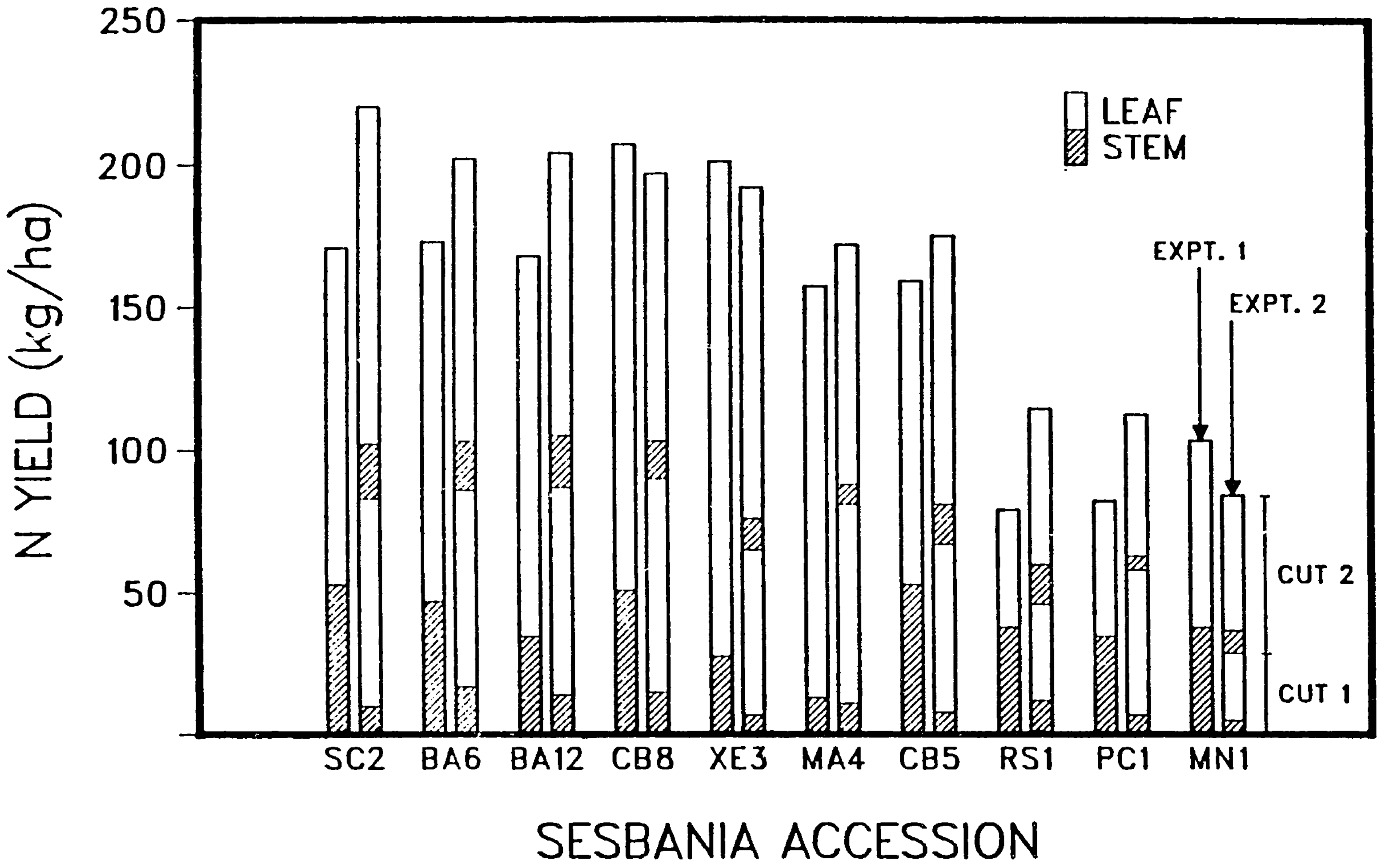

Figure 4. Nitrogen content (above-ground growth) of Sesbania accessions in two concurrent experiments. Experiment 1 (left bars) was harvested 94 days after planting. Experiment 2 (right bars) was harvested twice, at 49 and 84 days after planting.

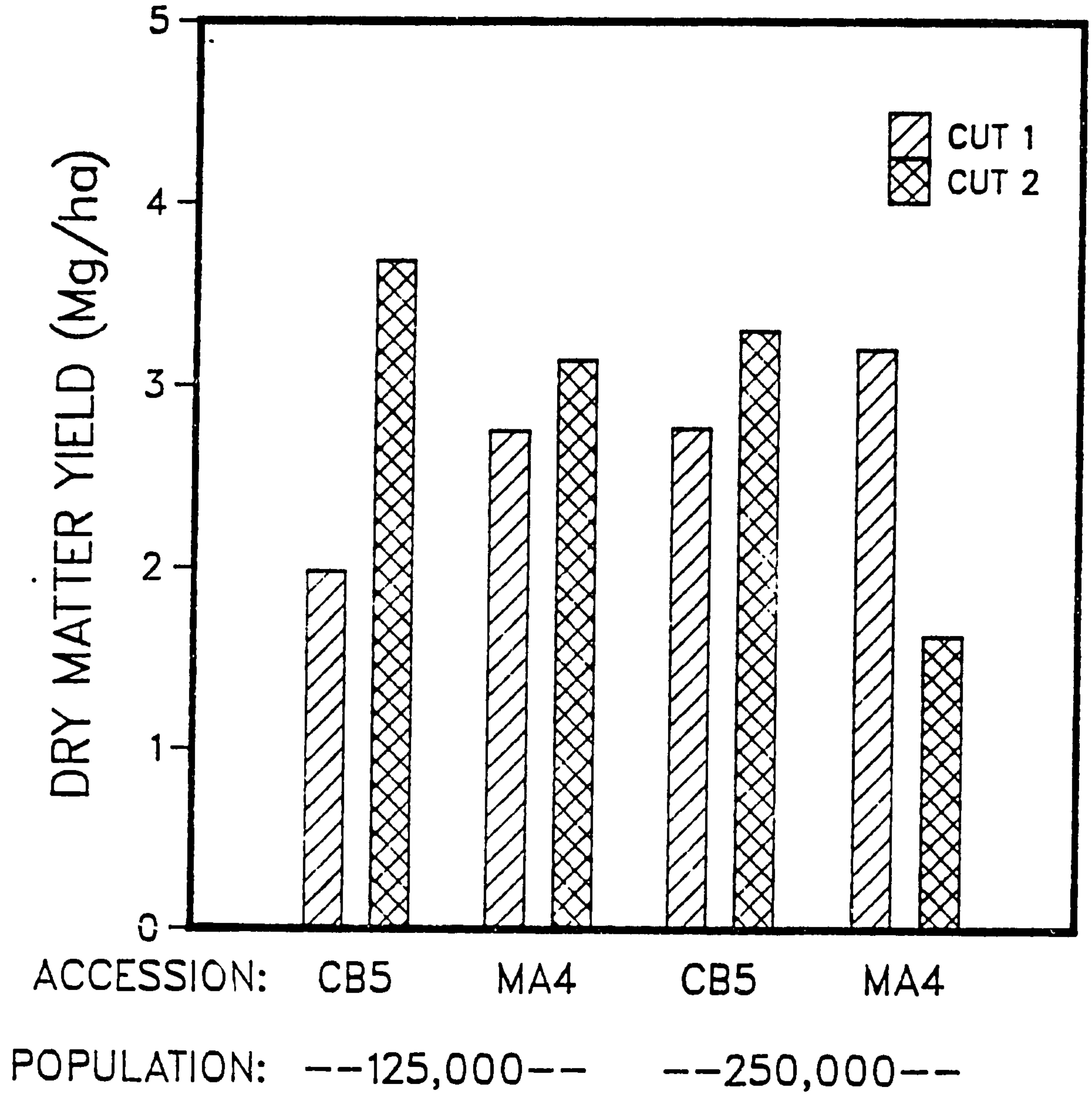

Figure 5. Yield of two Sesbania accessions having different flowering periodicity and sown at two population densities. Cut 1 was 49 and Cut 2 was 84 days after planting.

Table 1. Reported yields of Sesbania species.

Species	Growth Period days	Fresh Weight Mg/ha	Growth Rate kg/ha/day	N Content kg/ha	Reference
bispinosa	-	24.8	-		Singh & Sinha, 1962
"	52	14.3	280		Chandnani, 1954
"	60	25.0	420	120	Khind, 1982
"	75	28.7	380	104	IRRI, 1963
"	75	37.4	500	122	"
"	84	25.5	300		Panse et al., 1965
"	98	25.9	260		"
"	98	28.6	290		"
"	102	38.7	380		"
"	102	58.8	580		"
"	60	10.7	180		"
"	75	34.3	460		"
"	-	16.5	-		Van de Goor, 1954
"	-	12.6	-		"
"	-	23.4	-		"
"	-	14.9	-		"
"	74	20.0	270		Gaul et al., 1976
"	45	15.6	350		Khind et al., 1983
"	60	28.9	480		"
"	56	30.0	536		Katiyar, 1969
sericea	84	26.8	320		Panse et al., 1965
microcarpa	75	17.5	230	88	IRRI, 1963
macrocarpa	84	22.1	260		Panse et al., 1965
"	63	27.6	439		Anon., 1931)
speciosa	119	46.8	390		"
"	75	15.7	210		"
"	84	25.5	300		"
"	60	40.3	671	87-136	Nair et al., 1957
"	120	56.0	467		Mudaliar, 1954
"	240	96.8	403		"
sesban	75	51.5	687	202	IRRI, 1963

Table 2. Sesbania accessions grown.

Accession Code		Name as Received		Geographical Origin	Donor	Other Designation
BA3		bispinosa	?	India	CRRI, India	
BA4		aculeata	?	S. China		
BA5		aculeata	?	India		
BA6	*	-	?	India	CSSI, India	
BA7		bispinosa	?	India	CSIRO, Aust.	CPI 71021
BA8		concolor	+	India	CSIRO	CPI 71022
BA12	*	-	?	S. Asia		
CB1		cannabina	?	India	USDA	PI 180050
CB2		cannabina	?	Hainan, China		
CB3		cannabina	?	N. Vietnam		
CB4		cannabina	?	S. Vietnam		
CB5	**	cannabina		Australia	Waimea Arboretum	74s76
CB6		cannabina	?	Australia	CSIRO	CQ 1424
CB7		cannabina	?	Australia	CSIRO	CQ 1445
CB8	*	cannabina	?	Botswana	CSIRO	CPI 78174
CH1		cochinchinensis	?	Hong Kong	CSIRO	CPI 91846
DP2		punicea		Rep. S. Africa	Natal Herbarium	
EX3		exasperata		Surinam	CSIRO	CPI 63925
MA4	**	-	?	Arizona, USA	Dessert Seed Co.	
MN1	*	macrantha		Rwanda		
MP1		microphylla		Zambia	CSIRO	CPI 39939
PC1	*	pachycarpa		Congo	USDA	PI 247856
PC2		pachycarpa		Senegal		
PC3		pachycarpa		Senegal	CSIRO	CPI 50978
RS1	*	rostrata		Senegal		
SC1		sericea	?	Australia	USDA	PI 284844
SC2	*	sericea	?	Surinam	CSIRO	CPI 63926
SM1		simpliciuscula	?	Australia	CSIRO	CQ 1425
SP1		speciosa		Sri Lanka	USDA	PI 219851
TP1		tetraptera		Swaziland	USDA	PI 365143
VC1		vesicaria		Texas, USA		
XE3	*	-	?	Taiwan ROC	Taiwan Agric. Res. Inst	
XE7		-	?	"	"	
XE8		-	?	"	"	
XP		emerus	+	Peru		
SB10	*	sesban		Venezuela	CSIRO	CPI 28114

Notes: S. speciosa had been introduced to Sri Lanka from E. Africa.

* indicates accessions used in Experiment 2; SB10 was not used in Experiment 1.

** indicates cutting trial accessions also planted at double population.

? name uncertain; see text.

\+ accession identified (XP = S. emerus, Reinaldo Montiero, pers. comm.) or corrected (BA8 was received as S. bispinosa, G.P. Lewis, pers. comm.).

Table 3. Yield data for 35 _Sesbania_ accessions grown for 14 weeks.

Species Accession Code**	Total dry Matter*	Total Fresh Matter	Total Nitrogen	Stem Specific Gravity*	Leaf/stem Proportion Dry Matter	Leaf/stem Proportion Nitrogen
	Mg/ha	Mg/ha	kg/ha	kg/m^3		
CB7	17.02	54.79	245	241	0.61	3.1
CB6	16.55	53.44	231	216	0.47	2.2
CB8	15.74	49.27	207	200	0.43	3.1
EX3	15.72	50.21	198	211	0.33	2.0
CB2	15.14	46.46	197	190	0.55	3.6
XE7	15.00	46.77	197	185	0.51	3.7
CB3	14.89	46.67	201	226	0.42	2.4
SC1	14.05	43.85	174	222	0.42	2.5
BA5	14.01	43.75	175	208	0.40	2.5
BA6	13.82	44.58	173	219	0.42	2.7
BA4	13.80	43.54	186	222	0.63	5.1
SC2	13.56	43.44	171	214	0.33	2.2
CB4	13.11	40.94	158	196	0.41	2.9
XP	12.96	50.94	181	158	0.40	2.1
XE3	12.94	42.29	201	221	0.76	6.2
BA12	12.54	45.73	168	224	0.56	3.7
BA3	12.34	42.29	179	177	0.33	1.2
CB5	12.30	40.94	159	266	0.45	2.0
RS1	12.10	35.94	79	169	0.16	1.0
BA8	11.16	34.90	153		0.44	3.0
XE8	10.79	37.40	174	183	0.75	5.0
SM1	10.65	36.15	149	235	0.47	2.2
CH1	9.98	36.77	151	189	0.57	2.5
BA7	8.93	23.54	151	210	1.40	8.8
CB1	8.86	26.46	191	181	1.10	10.0
MA4	8.19	24.27	157	176	1.10	11.0
MN1	7.66	33.65	103	189	0.35	1.7
SP1	7.42	28.65	57	153	0.32	1.6
PC2	6.67	23.96	102	284	0.29	1.4
MP1	6.53	21.56	65	185	0.36	2.4
TP1	6.19	22.19	77	167	0.75	5.4
PC1	5.46	22.29	82	235	0.30	1.4
PC3	4.74	20.31	68	272	0.29	1.9
VC1	3.36	13.44	56		0.96	5.4
DP2	2.24	8.02	33		0.51	1.6

** see Table 2.

* Stem specific gravity expressed in bone dry kg/m^3. Dry matter yield values were derived from samples dried in crop drying oven and containing 5-10% moisture. Samples for specific gravity were taken 6 months after sowing.

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PRODUCTIVITY OF *SESBANIA* SPECIES

2. PERENNIAL SPECIES FOR FODDER PRODUCTION.[1]

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Abstract

Sesbania species accessions were evaluated for fodder production in comparison with other nitrogen fixing trees over a series of harvests during 1 year from planting. *Leucaena leucocephala* became infested with a newly introduced *Heteropsylla* sp. pest, and *Calliandra callothyrsus* and *S. grandiflora* appeared to be sensitive to drought stress. Variations in *S. sesban* accessions were observed: some were fast-growing initially, while others were slower to establish but had increasing yields with later harvests and produced comparable total yields in the growth period. High-yielding *S. sesban* accessions produced >20 Mg/ha dry matter in 5-6 cuts during the establishment year.

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[2] Research Associate and Professor of Agronomy.

Introduction.

Sesbania species are most commonly known as green manures because they are so used in Asia. These fast-growing legumes may also be sources of pulp fiber, fuelwood, and fodder. We reported previously on the relative productivity of different annual species (Evans and Rotar, 1985). The genus also contains perennial species, shrubs and trees, many of which have not yet been evaluated agronomically. Lesser-known species which are localized in occurrence include: 1) those native to the genus' African center of diversity (Gillett, 1963), 2) the Hawaiian endemic S. arborea (Char, 1983), and 3) the Australian species, S. formosa (Burbidge, 1965). Two others, more widely known, have pantropic distribution due for the most part to spread by man: S. grandiflora has been a candidate tree for short-rotation fuelwood and pulpwood forestry (NAS, 1979, 1981); S. sesban's potential as a multi-purpose tree has also been recognized (NAS, 1983). Both have been grown as sources of green leaf manure and high-protein animal fodder, and their characteristics and uses for these purposes are detailed in a forthcoming article on the genus (Evans and Rotar, in preparation). The present report describes an experiment evaluating 17 Sesbania species accessions and two non-sesbanias, Calliandra callothyrsus and Leucaena leucocephala, for fodder production.

Materials and methods.

Details of the soil (a Vertic Haplustoll, Waialua series) at the site on coastal, windward Oahu were given elsewhere (Evans & Rotar, 1985). Plots consisted of 4 rows, each 5 m long spaced 1 m apart, with the inner 3 m of the central 2 rows serving as the harvest area. Seed was scarified by soaking in concentrated sulfuric acid for 15-30 minutes depending on the accession, followed by rinsing in water. Sesbanias were inoculated with *Rhizobium* in a peat carrier with gum arabic solution as a sticker. Calliandra and leucaena were not inoculated, but indigenous soil *Rhizobium* for the latter were known to be present. *S. grandiflora* and *S. formosa* were sown 25 cm apart in the rows (population 40,000 hills/ha); all other entries were sown 20 cm apart (population 50,000 hills/ha). Seed was sown into slightly moist soil at a depth of about 2.5 cm, and the field was irrigated the following day, June 24, 1983. For the next 10 months, until water supplies dwindled due to failure of winter rains, irrigation was applied by overhead sprinkler every 10-14 days. Total rainfall during the 12 months following planting amounted to 61 cm, with <2 cm of rain in each of the last 2 months of that period.

The experiment was in an augmented, randomized block design; there were 10 main entries having 3 replications, and 9 unreplicated augment entries distributed among the blocks. Harvesting was done on an individual accession basis: when the stands reached a height of approximately 2 m, they were cut back to a height of 50 cm above ground level. Two entries (CAL and

T02) grew slowly in terms of vertical height and were cut when stands were about 1.5 m high. Our harvest method was intended to represent the "cut-and-carry" method used by developing country farmers maintaining small-scale livestock enterprises. Harvesting was done with hedge shears having scolloped notches in the cutting blade edges, which aided in cutting woody stems 2-3 cm in diameter. As done by us, harvesting these materials was a 2-person task, with one person gathering together and holding the branches of one or more plants, while the second person cut with the shears from the other side of the row. This method allowed more precise cutting and neater stacking of cut materials than would be possible with one person. Subsamples taken from the harvest area were dried in a crop drying oven at 50 C. After drying, stems were separated from the forage fraction, which consisted of leaves, leaf rachises, and stems 3 mm or less in diameter; stem and forage fractions from selected harvests were analysed separately for chemical composition. Forage fractions from selected accessions and harvests were submitted to the University of Hawaii Feed and Forage Analyses Program for determination of nutrient composition.

Accessions grown are listed in Table 1. Of the four _S. grandiflora_ accessions, GL1 is the red-flowered type sometimes referred to as variety _coccinnea_, while GL5, GL7, and GL8 are white-flowered. _S. sesban_ (L.) Merr., previously called _S. aegyptiaca_, is quite variable, with subspecies (_sesban_, _punicea_) and varieties (_sesban_, _nubica_, _bicolor_, _zambesiaca_) (Gillett,

1963) as well as close relatives (e.g. S. keniensis Gillett and S. goetzei Harms) which have species status and may be indistinguishable to the casual observer. There are several types of S. sesban in our collection. Accessions SB1, SB2, SB9, and SB12 form a group apparently similar to S. sesban var. nubica, and have all been so identified by G.P. Lewis at the Royal Botanic Gardens, Kew, England, working with herbarium vouchers we provided. Since Gillett has made species distinctions based upon correlations of morphological characteristics with observations of ecological requirements, i.e. phenotype, we must suggest on the basis of plant performance in our experiments that this group is not homogeneous. SB1 and SB2 were similar in performance, but SB9 and SB12 were different from these as well as from each other.

Other S. sesban accessions in our experiment resembled one another in gross morphology and were distinct from the group just discussed. Their herbarium vouchers have been identified as either S. sesban var. sesban (SB10, SB13, XW), or var. bicolor (SJ2), or possibly var. bicolor (SB11, X2), because of variation in flower color intensity among plants (pale yellow to orange, with various amounts of dark purple, from light speckling to solid, on the standard petals). Under the uniform environmental conditions of our experiment, we found some variation in yield and growth rate but did not observe much difference in plant form (leaf size, branching habit) within this latter group of S. sesban accessions.

Results.

Yield data for the individual entries is from harvests varying in number and interval during one year from sowing. These variations are the result of harvesting by growth stage, when plants reached a height of 2 meters, rather than a specific time interval. Figure 1 shows the harvest intervals (1a) and the cumulative dry matter production (1b) during the experimental period. Because the use of growth rates helps to overcome difficulties in comparing growth among varying harvest intervals, Figure 2 shows cumulative growth rates of selected entries over time. Table 2 presents statistical rankings for cumulative growth rates (cf Fig. 2), growth rates within harvest intervals, and dry matter yields of harvests (cf Fig. 1b) for the replicated entries. The comparisons of yields and rates in Table 2 are confounded by intervals between harvests and time, yet are given to illustrate trends and differences among entries.

For example, considering the replicated accessions in Table 2, accessions SB10 and especially SB13 had high initial growth rates so that superior cumulative growth rate values were maintained over 5 harvests despite declines in growth rates and yields for individual harvests, perhaps due to drought. SB9 had an initial growth comparable to most other entries, but its lack of successful adaptation became clear during the first regrowth period. Although leucaena started slowly, it grew vigorously after the initial cutting and showed indications of being high yielding, as expected, at its 3rd and 4th harvests, but thereafter its yield declined with the onset of a psyllid pest infestation. *S. grandiflora*'s growth was intermediate and appeared particularly sensitive to the increasingly drier soil conditions during the experimental period. *S. formosa* growth was poor. A dramatic growth response is observable in SB1, which in contrast to SB13 grew slowly at first with growth steadily increasing as the plants developed, in spite of progressively drier conditions. Calliandra had high yields at its two harvests, but growth rates were not high.

Nitrogen percentages of forage and stem fractions are given in Table 3. Except for calliandra, values for leaf N are means of 3 analyses per species (from harvests 1, 2, and 3) and values for stem N are from harvest 2. Generally, harvested material contained slightly more leaf fraction dry matter than stem. Average for all harvests and species was 55% leaf; leucaena and the sesbans SB10 and SB13 were about 60%, and SB1 was 46% leaf.

Nutritive composition of selected entries is given in Table 4. Samples were leafy material (leaves + branches 3 mm or less in diameter) from the 2nd or 3rd harvest, taken after a regrowth period of 8-9 weeks from the previous harvest, except for calliandra and *S. arborea*, for which samples were from the 1st harvest taken 26 and 21 weeks after planting, respectively.

High-yielding plants. The high-yielding entries produced yields ranging from 12.5 to 20.5 Mg/ha dry matter during the experiment year (Fig. 1b) and may be suitable as fodder producing trees for sites and management regimes similar to ours. In terms of productivity, they may be ranked S. sesban > L. leucocephala > S. grandiflora = C. callothyrsus. During the trial period, these entries afforded 4-6 harvests, with the exception of calliandra.

The highest yielding group were the S. sesban entries SB1, SB2, SB10, SB11, and SB13. These produced over 20 Mg/ha dry matter during the establishment year and had growth rates permitting harvests every 8-9 weeks. Initial growth rates of SB10 and SB13 were comparable to those of annual Sesbania species, as represented by SB3 (Fig. 2). Accession SB1 was unique among entries in maintaining steady increases in yield and growth rate with successive harvests (unreplicated SB2 was similar in performance). Dry matter yield of SB1 at each individual harvest increased linearly with time ($y = 1734 + 11.4x$, $R^2 = 0.917$).

The remaining S. sesban accessions varied in their performances. Accessions XW and SB12 were similar to leucaena in cumulative growth rate and in yield. The unreplicated SJ2 and X2 were similar to each other in productivity and intermediate between the latter two sesbans and the higher-yielding SB13.

S. grandiflora was represented by 1 replicated and 3 unreplicated entries. The unreplicated GL1 was slower-growing than the others, cut only 3 times compared to their 4. The other augments, GL7 and GL8, were similar in performance to the replicated GL5. *S. grandiflora* had a high moisture content, averaging 81% over all harvests compared to a mean of 76% for all entries.

Calliandra callothyrsus was much slower to establish than other entries. The first harvest was taken 6 months after planting when it averaged about 1.5 m height; the 2nd harvest was taken 132 days later when stands regrew to 1.8 m height. Yields at these harvests were high, averaging 5.0 and 7.3 Mg/ha dry matter, respectively; total yield of the two harvests was similar to *S. grandiflora* cut 4 times (Fig. 1b). The harvested material averaged 66% moisture content, conspicuously lower than the other entries which had average values in the range of 75-80%. Although *Calliandra* was not inoculated with *Rhizobium*, there was no indication of nitrogen stress. *Calliandra* growth seemed limited by the dry conditions which prevailed following its 2nd harvest, and although the stands survived, growth was slow.

Leucaena leucocephala was slower to establish than most of the sesbanias, producing lower yield at the first harvest. During its first regrowth period, growth rate increased remarkably but this trend did not continue (Fig. 2), as it became heavily infested with *Heteropsylla* species at about the time of the 4th harvest (approximately day 300), and yield fell off thereafter (Table 2). This psyllid pest, new in Hawaii, fed on leucaena (but not on sesbania or calliandra) by sucking at sites of active growth, preventing normal leaf development. The pest occurred in such numbers that leucaena growth was severely restricted.

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Low-yielding plants. Entries which performed poorly were the accessions SB3, SB9 (S. sesban), TO2 (S. arborea), and FO2 (S. formosa).

The unreplicated SB3 was apparently not S. sesban; it demonstrated annual growth habit by flowering and setting seed copiously after the 1st harvest and declining in growth after the 2nd and final harvest was taken. SB3 had a high growth rate (Fig. 2) and produced a total of about 7 Mg/ha dry matter in 2 harvests over approximately 3.5 months.

The unreplicated S. arborea proved to be poorly adapted to our site and management; it required 5 months to reach a height of 170 cm and regrew very slowly after it was cut. It is characteristic of the endemic Hawaiian Sesbania species, most of which are probably endangered species, that they do not readily adapt to environments differing from their natural range (W. Char, pers. comm.).

S. formosa also proved to be unsuitable. Only 3 harvests were taken in the experimental period, v.s. 4 harvests for S. grandiflora. Yield was less than for the latter, and regrowth rates were therefore low. Leaf N values were almost a full percentage point less than those for S. grandiflora (Table 3). Our observation of S. formosa in Hawaii has led us to conclude that this tree is better suited for wood production than for fodder production; it appears to be better adapted to semi-arid sites than its near relative, S. grandiflora.

The S. sesban accession SB9 grew poorly, apparently because it lacked effective symbiotic Rhizobium associations. In a previous strain X species screening of sesbanias and 6 Rhizobium isolates from sesbanias, SB9 was either not nodulated or sparsely and ineffectively nodulated (M. Habte & Evans, unpublished). In the present experiment, leaf N values for SB9 were low (Table 3) and decreased with successive harvests to less than 3%; conversely, leaf P percentages increased to quite high levels. After the 3rd harvest, regrowth was very slow and plants were chlorotic. A few individual plants continued to grow, but the majority died out.

Discussion.

Wilt caused by *Sclerotium rolfsii* affected 5-50% of plants in plots of *Sesbania* accessions during months 10-12 of the experiment, and was observed to occur following cuttings. With the harvest of almost all the foliage at the time of cutting, it is possible that increased soil temperatures in the dry upper soil layer encouraged colonization by the fungus at a time when the plants were weakened. Our practice of removing understory weed growth from inter-row spaces following cuttings also contributed to raising soil temperatures and decreasing surface soil moisture. Neither leucaena nor calliandra was affected by the fungus. In fodder production schemes using sesbanias, it is possible that during periods of dry weather and high surface soil temperatures, incidence of wilt can be minimized by partial, selective cutting to maintain shade for the soil surface and reduce shock to individual plants, and/or maintaining a grass understory.

We are not certain that we employed the optimum method of harvesting these materials as fodder. In mechanized production or in experimental trials it is difficult to harvest selectively. In developing countries, usually only the most edible portions of trees and shrubs are harvested; the intensity of defoliation of plants is modified at the discretion of the gatherer, and individual plants not at an optimum stage for harvest may be deferred. This type of harvesting resembles browsing by animals, and may be, though more laborious, a more optimal method of managing plants. On Molokai, Hawaii, S. arborea is browsed by cattle, axis deer, and feral goats, and plants survive many years as evidenced by trunk size. Although new growth at branch tips is regularly browsed back during dry seasons, the plants' structure is generally left intact. In India, Kareem (1967) recommended "careful picking of the leaves (of S. grandiflora) lest severity of picking harm the plant." Such "picking" would leave young stem tissue on the plants, with its relatively numerous meristematic sites from which new leaves and branches may arise. Arbitrary, take-all harvest removes these tissues. While this does not seem to deter regrowth in some plants, such as leucaena (unless cutting is too low, e.g. 10 cm or lower), or S. sesban (under our conditions), S. grandiflora may have been inappropriately managed in our experiment. Although it is sometimes maintained that this species does not regrow well after cutting, this may be more correct in regard to its coppicing response, i.e. the regrowth from stumps after cutting mature trees. We found that regrowth was good, perhaps because its stems were cut when the bark was relatively immature. We suggest that leaf production by S. grandiflora may be enhanced by harvesting methods designed to leave numerous young nodes on the plant, rather than repeatedly cutting all regrowth back to old tissue.

In conclusion, Sesbania sesban was found to have rapid growth and regrowth after cutting and to produce high yields of protein-rich fodder materials; some varieties of S. sesban were more productive than others during periods of drought. These materials were comparable in productivity, if not superior to Leucaena leucocephala and therefore are potentially important sources of supplemental ruminant feed which should be more widely considered for adoption. Calliandra callothyrsus and Sesbania grandiflora both grew more slowly at our site; they were moderately productive but their growth rates appeared to be more sensitive to soil moisture stress. Harvesting strategies to optimize fodder yields for S. sesban varieties and especially for S. grandiflora and Calliandra need development.

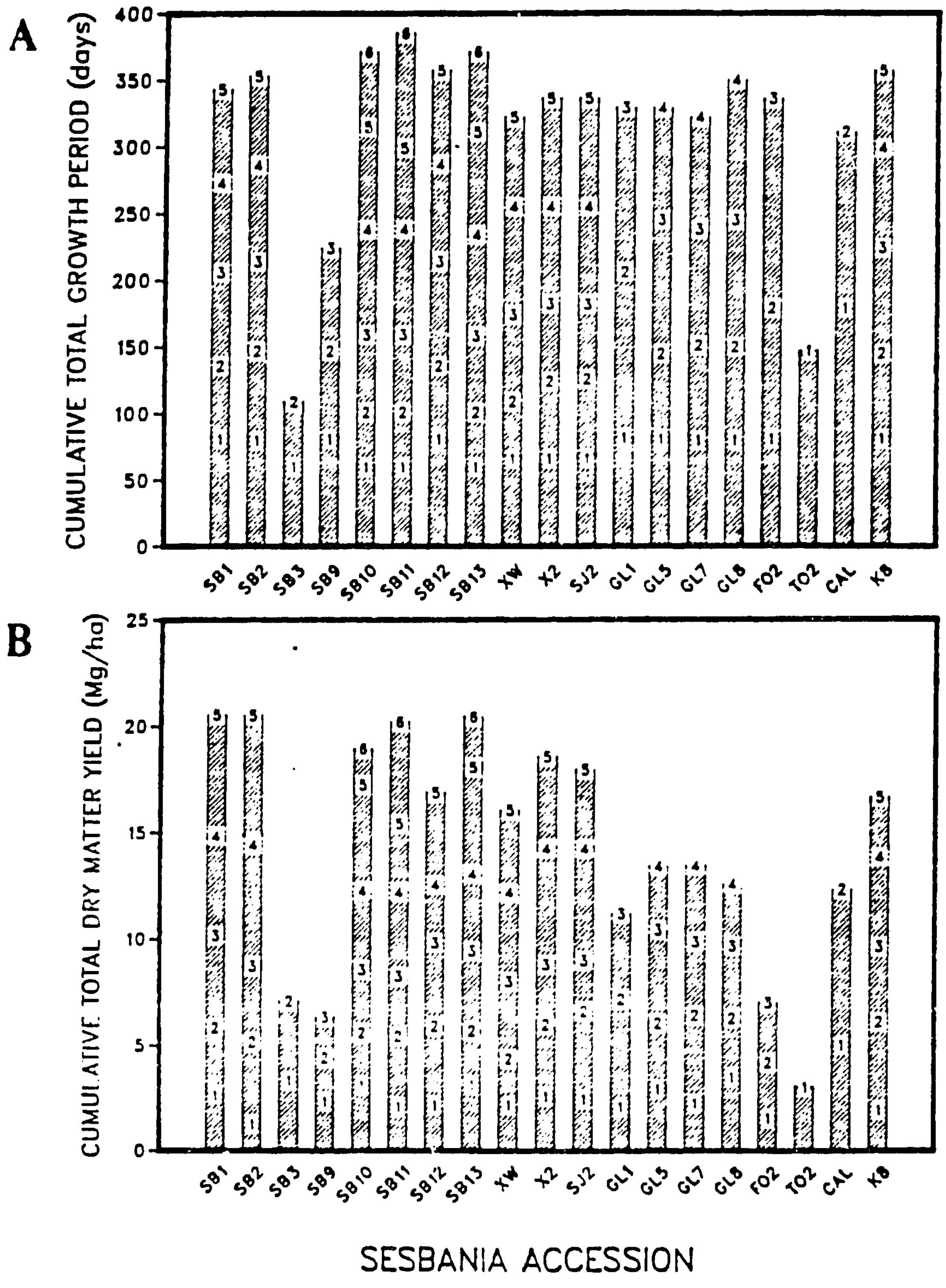

Figure 1. Harvest intervals (1A) and cumulative dry matter yields (1B) of Sesbania and other legume trees cut for fodder (see Table 1 for key to species accession codes). Numbers within bars indicate successive harvests taken during the 1-year period following sowing.

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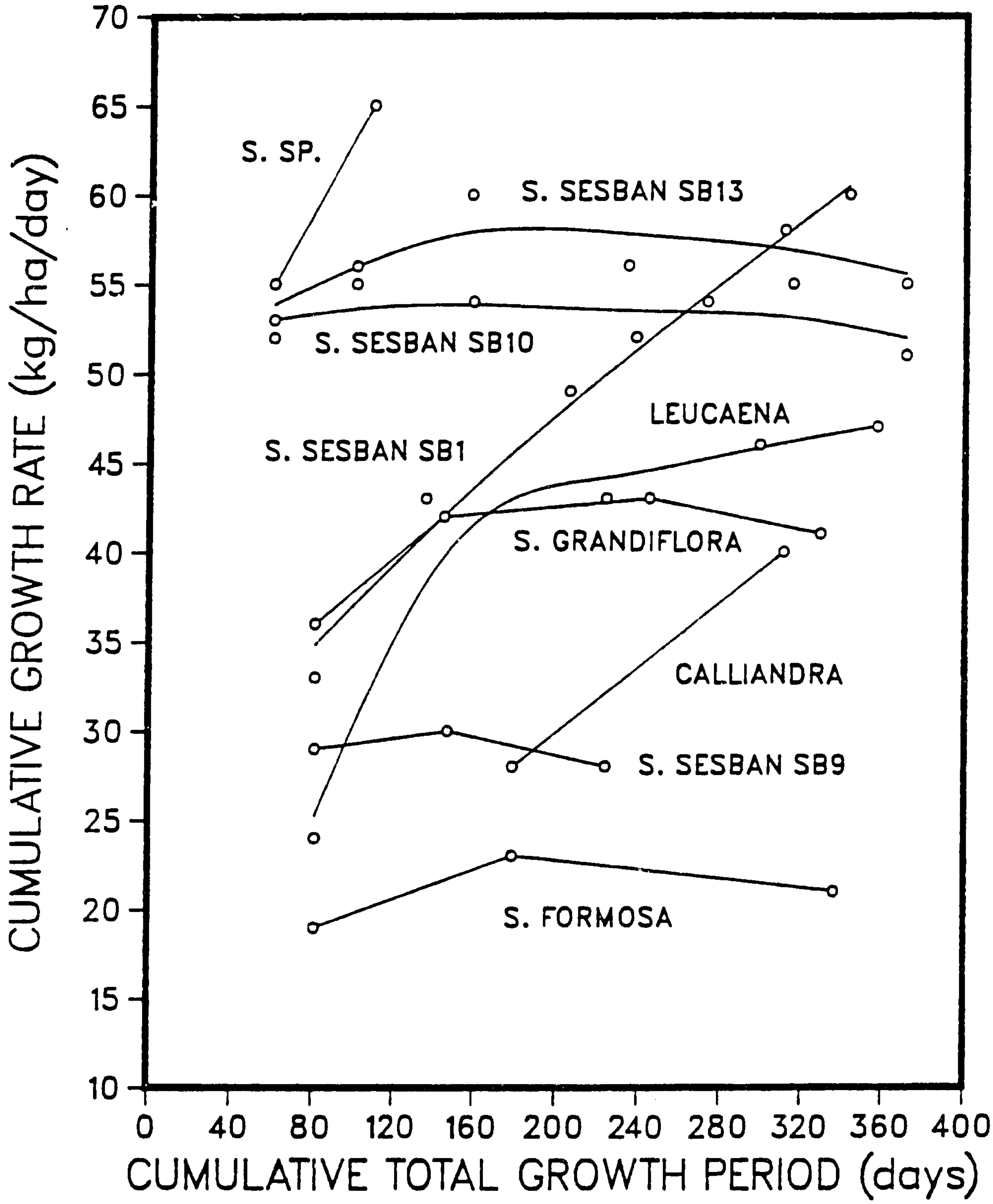

Figure 2. Cumulative growth rates of Sesbania and other legume trees cut for fodder at successive harvests (each data point represents a mean of 3 replicate plot yields per cut, except for the unreplicated Sesbania sp.).

Table 1. <u>Sesbania</u> species accessions compared for fodder production.

Accession Code		Name **	Geographical Origin***	Donor	Other Designation
SB1	*	Sesbania sesban	Kenya		
SB2		S. sesban	Congo	USDA	PI 247857
SB3		S. species	Okinawa	USDA	PI 233551
SB9	*	S. sesban	Rwanda		
SB10	*	S. sesban	Venezuela	CSIRO	CPI 28114
SB11		S. sesban	Burma	CSIRO	CPI 30774
SB12	*	S. sesban	Uganda	CSIRO	CPI 32223
SB13	*	S. sesban	Egypt	NifTAL	NFT 159
XW	*	S. sesban	Punjab, Pakistan		
X2		S. sesban	Brazil	CIAT	CIAT 7934
SJ2		S. sesban	Indonesia	CSIRO	CPI 34853
GL1		S. grandiflora	Oahu, Hawaii		
GL5	*	S. grandiflora	Guatemala	CATIE	CATIE 1147
GL7		S. grandiflora	E. Java, Indonesia		
GL8		S. grandiflora	W. Samoa		
F02	*	S. formosa	Australia	CSIRO	CQ 1146-26
T02		S. arborea	Molokai, Hawaii	USDA PMC	
CAL	*	Calliandra callothyrsus	Indonesia		
K8	*	Leucaena leucocephala	Mexico/Hawaii		

notes: * Designates replicated entries.
** Some species have been revised: SB3 was received as S. sesban, SJ2 as S. javanica.
*** Place of collection, or as given by donor.
Except for SB9, GL5, GL7, and F02, seed used was increased in Hawaii.

Table 2. Waller-Duncan K-ratio T tests* on data for each harvest (vertical columns) for dry matter yield and accumulation rates of *Sesbania* species, *Leucaena leucocephala*, and *Calliandra callothrysus*.

	cumulative growth rate					growth rate per harvest					dry matter yield per harvest				
Harvest**:	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Accession															
S. sesban SB13	a***	a	a	a	a	a	ab	a	bc	b	b	cd	abc	bcd	ab
S. sesban SB10	a	a	ab	ab	ab	a	abc	bc	bc	b	b	cd	bc	bc	ab
S. grandiflora GL5	b	b	c	d		b	c	c	c		b	c	a	cd	
S. sesban SB12	b	b	c	cd	c	b	abc	bc	c	bc	bc	c	ab	d	bc
S. sesban XW	b	b	c	bc	bc	b	bc	abc	b	bc	bc	d	abc	ab	c
S. sesban SB1	b	b	bc	a	a	b	abc	ab	a	a	bc	c	a	a	a
S. sesban SB9	bc	cd	d			bc	d	d			bc	d	d		
calliandra	bc	bc				bc	abc				a	a			
leucaena	bc	b	c	bcd	c	bc	a	c	b	c	bc	b	abc	ab	d
S. formosa	c	d	d			c	d	d			c	cd	cd		
LSD	12.9	9.6	8.0	6.6	7.0	12.9	12.2	13.8	12.1	6.4	1.26	0.83	1.04	0.97	0.93
	kg/ha/day										Mg/ha				

*SAS Institute, Cary, N.C., U.S.A.
** Harvests were not taken at the same time intervals for all entries (cf Fig. 1).
*** Unlike letters indicate significant differences in each vertical column.

Table 3. Nitrogen percentages of yield fractions of tropical leguminous trees cut for fodder.

Species accession	leaf N %	stem N %
Sesbania grandiflora	4.16	1.08
S. formosa	3.26	0.80
S. sesban SB9	3.09	0.62
S. sesban XW,X2,SJ2	4.38	0.71
S. sesban SB1,2	4.64	0.73
S. sesban SB10,11,13	4.55	1.01
Leucaena leucocephala	4.74	1.20
Calliandra callothyrsus	3.20	0.79

Table 4. Nutrient composition* of leafy fraction of tropical leguminous trees cut for fodder.

Species accession	Ash	CP	EE	NDF	ADF	PML	C	Ca	P
Sesbania sesban SB1	9.1	31.1	3.9	30.6	20.6	5.0	15.6	1.01	0.46
S. sesban SB9	12.0	18.9	3.2	29.6	21.4	5.4	16.0	2.02	0.94
S. sesban SB10	9.9	31.8	4.0	27.6	19.6	4.7	14.9	0.99	0.48
S. sesban SB12	9.3	25.2	3.1	34.1	25.8	6.9	18.9	1.22	0.43
S. sesban SB13	9.7	31.9	4.4	25.7	18.3	4.4	13.9	1.17	0.48
S. grandiflora GL5	10.0	27.6	4.3	29.5	21.4	5.1	16.3	1.32	0.44
S. formosa	8.2	21.3	3.3	46.1	38.8	16.6	22.4	1.27	0.43
S. arborea	9.4	18.4	2.5	43.1	33.6	8.7	24.9	1.56	0.29
Calliandra callothyrsus	7.5	19.5	2.4	49.0	30.8	16.6	14.2	1.25	0.34
Leucaena leucocephala	8.0	28.4	4.2	36.2	23.1	7.4	15.7	1.02	0.29

* Percentage on dry matter basis.
CP = crude protein; EE = ether extract (crude fat); NDF = neutral detergent fiber (total cell wall constituents); ADF = acid detergent fiber; PML = permanganate lignin; C = cellulose; Ca = calcium; P = phosphorus.

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