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Forages for Plantation Crops

Proceedings of a workshop,
Sanur Beach, Bali,
Indonesia 27-29 June, 1990

Editors: **H.M. Shelton and W.W. Stür**

Contents

Foreword

The countries and populations of Southeast Asia and the South Pacific are rapidly improving their economies and their demand for meat is increasing. Projections of population increase to the year 2000 indicate that demand for meat will not be met and the gap between total requirement and local production will be even greater than it is currently. There is little incentive for increased commercial ruminant production in many countries and animal products are usually produced as secondary by-products of other more important agricultural activities. Clearly this situation will change as policy makers perceive the negative influence of increasing beef imports on their economies.

The shortage of land in many countries ensures that the obvious potential for integrating ruminants with the extensive areas of plantation crops in the region will be exploited. However, the successful exploitation of this resource requires that suitable forage species and management strategies are available. It is with this objective that the ACIAR Project 8560 on Improvement of Forage Productivity in Plantation Crops was initiated in 1988.

The research work of the ACIAR Project Group that is presented in these Proceedings is the result of a genuinely cooperative effort. We have worked closely on the planning and implementation of the program and have attempted to integrate our respective resources in the most efficient manner. We hope that the value of this approach will be evident to our readers.

This publication of the Proceedings has two objectives. It allows the presentation of the first two-and-a-half years of our work. Just as importantly, it has provided the opportunity for our research group to meet other international scientists and share experiences on the topic of forages for plantation crops.

The ultimate objective of the work is to provide the information needed by extension workers and farmers to increase the productivity of ruminants in plantation crops. The opportunity for increasing ruminant production in this way is considerable indeed.

H.M. Shelton
W.W. Stür

Editors

Acknowledgments

Careful planning and good organisation were the keys to the success of our Workshop enhanced by the location in beautiful Bali. A number of institutions and individuals assisted greatly with the organisation of the meeting.

We thank the Rector of Udayana University, Professor I.G.P. Aduyana, and the Dean of the Faculty of Animal Husbandry for kindly agreeing to host the Workshop in Bali.

We are especially indebted to the untiring efforts of Professor I.K. Rika and his team who organised the venue for accommodation, registration, meeting room, distribution of papers, coffee breaks and pre- and post-workshop field trips. We also thank Mr I.K. Mendra, Mr Oka Nurjaya and his wife Mrs Sri Agung.

It was a pleasure for the editors to prepare the papers for these Proceedings, and we are grateful for the creative efforts of all authors who contributed so much to the Workshop through their presentations and informal comments.

Finally, we wish to thank the Australian Centre for International Agricultural Research (ACIAR), and the ACIAR Forage Coordinator, Dr G.J. Blair, for their sponsorship of the Workshop.

We believe that this volume represents an important addition to the literature and to our understanding of the problems and prospects for promoting forages in plantation crops.

The Editors

The ACIAR Forage Program

Graeme Blair*

An increase in human population in the developing world has resulted in a concomitant increase in small and large ruminants. This has resulted in severe competition between crops and animals and has led to an increasing demand for forage resources, generally on land of lower production capability. In northern Australia the cattle population has increased substantially as a result of new technologies such as new forage species and animal supplementation. This has put increasing pressure on rangelands in that region. In addition, the increase in interest in crop agronomy that occurred in Australia during the 1970s has resulted in a fall-off in the number of scientists involved in pasture and forage research.

Australia has a comparative advantage in pasture and forage research in that the country is generally covered by poor soils and has an unreliable climate. This has led to the need to introduce forage species into Australia to build up its animal industry. Early efforts by Australians in forage development in the developing world were hampered by the idea that pastures are grazed. Clearly, in areas of high population density other management strategies, such as cut-and-carry, are an important part of the production system. The ACIAR Forage Program considers a wide range of forage alternatives.

Goals

The Forage Program is coordinated via a Liaison Project and serves as an interface between the animal and plant production programs and soil management and plant nutrition. The major focus of the program is the adaptation of forage plants to particular niches within production systems in Southeast Asia, the South Pacific and South Asia. Research and development projects there are supported by a newsletter and information network.

The overall goal of the Program is to produce forages at little or no cost, and this production should compete minimally with food crops. This means that production of forages is usually confined to marginal soils which creates special problems for their growth and persistence. Forage production should be part of a sustainable agricultural system and, in this regard, the Forage Program has close linkages with the soils and plant nutrition programs. In the area of acid soil development and management, the Forage Program is undertaking studies of plant adaptation to infertile soil conditions. This is complemented by studies of the chemical constraints to plant productivity being undertaken in the soils program.

Priorities and Their Rationale

The Forage Program consists of four projects. These are designed to select forages for large and small ruminants and cover the adaptation of shrub legumes to acid soils, forages to shade situations under plantations and to saline/sodic soil conditions. In addition to these programs, a project on adaptation of forages to acid soils in Southern China is being undertaken.

The projects within the Forage Program are:

8560 improvement of forage productivity in plantation crops;
8619 forage/shrub production from saline and/or sodic soils in Pakistan;
8836 production and utilisation of shrub legumes in the tropics; and
8925 forage development on red soils of South Central China.

Management

The Forage Program is coordinated by Dr Graeme Blair, a half-time coordinator seconded to ACIAR. Dr Blair is based at the University of New England.

Major Achievements

In developing countries

The production and utilisation of the shrub legume project has identified tree and shrub species for marginal tropical soils. An important contribution in this area is that the projects have identified species which can replace the tree legume *Leucaena leucocephala* which has been devastated by an insect pest in many parts of the tropics. Current studies are investigating the management and the feeding value of such replacement species.

Project 8619 has taken Australian saltbush (*Atriplex* spp.) to Pakistan and identified promising species for use on saline soils in that region. Such species will have a major impact on the productivity of these areas.

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Significant areas of Malaysia and Indonesia are covered by plantation crops such as oil palm, rubber and coconut. In these areas substantial inputs of herbicides are needed to control weeds. Project 8560 has identified forage species that will grow in these shaded environments. This has the potential substantially to increase sheep production under these crops, and consequently could lead to a reduction in spraying costs and an increased diversification of income.

Substantial areas of South Central China have severely eroded acid soils. Project 8925 has characterised the climate of these regions and selected forage species capable of growing under such adverse soil and climatic conditions.

The Forage Program has produced an ACIAR proceedings, 'Forages in Southeast Asia and South Pacific Agriculture', which has become a widely quoted source of forage information in the region. In addition, the Program has brought together the Consultative Group on International Agricultural Research (CGIAR) and Australian research institutions involved in forage germplasm storage, distribution, evaluation and multiplication. This has resulted in a proposal being put to the Australian International Development Assistance Bureau (AIDAB) for future funding in this area of forage R&D. In addition, Dr Blair has been acting as Chairman of the Organising Committee for the ACIAR-SEARCA (Regional Center for Graduate Study and Research in Agriculture) International Workshop on 'Technologies for sustainable agriculture on marginal uplands in Southeast Asia' held in the Philippines in December 1990.

Because of the need to assess forage species over a number of seasons and locations, forage projects are generally of a longer-term nature than other projects in ACIAR. This means that at this stage in the life of the Forage Program there is little direct evidence on the economic impact of the projects.

The Forage Program has had a major impact on institutional capacity-building in Indonesia, Malaysia and Pakistan. The collaborative mode of the ACIAR projects has given researchers in these countries a better appreciation of the important link between forage germplasm selection and animal production systems. The provision of small items of equipment and assistance in the modification of existing techniques has allowed increased output from basic facilities in these countries.

The distribution of ACIAR Forage Newsletter and the compilation of a forage database has led to improved links between forage researchers in Southeast Asia and the South Pacific. This means that researchers in the region have greater access to Australian expertise within their own region.

In Australia

Leucaena leucocephala has been planted in significant areas of Northern Australia as a fodder supplement for cattle. The same inspect pest that attacked this species in Southeast Asia is now present in Australia and the inputs from Project 8836 are allowing an introduction of new tree and shrub germplasm into Australia. The research on salt-tolerant forages (Project 8619) has linked with research funded by the Australian Wool Corporation to select more productive and persistent *Atriplex* species for use in saline areas of Western Australia.

The Forage Program has assisted the institutions involved in the projects in Australia to increase their capacity for forage research primarily by the employment of research fellows. This has provided a valuable learning experience for younger scientists. Projects in universities have benefited from a closer contact with agriculture outside Australia. This has led to a broadening of the subject matter taught in forage courses in these universities.

Major Constraints

The major constraint to the Forage Program is the small pool of Australian scientists who remain in forage research, and their availability to work in collaborative projects. Many forage scientists in Australia are heavily committed to research funded by industries such as wool and meat. This, together with the reduction in activities in pasture research in Australia in the 1970s mentioned earlier, has led to a manpower shortage of experienced scientists in forage research. The ACIAR projects already under way are contributing in a small way to reversing this trend. The long-term nature of forage selection, evaluation, and introduction into farming systems means that a long-term commitment to forage R&D is required. To date this has been achieved by undertaking replacement projects in areas that show promise. The future funding of these longer-term activities requires careful evaluation.

Future Strategies

It is hoped that the Forage Program will be able to undertake a moderate expansion in the future to encompass projects on seed production and establishment which are two key areas with a major bearing on the success of any forage introduction and utilisation program.

It is envisaged that the program will link more closely with both the Animal Program and the Soils and Plant Nutrition Programs. This will allow the development of forage systems within farming systems and sustainable frameworks. It is envisaged that this will be achieved through joint projects across program areas.

Evaluation of forages growing in small plots under coconuts in North Sulawesi, Indonesia.

Screening for shade tolerance at the University of Queensland Research Farm at Redland Bay, Australia.

Sheep grazing in an 8-year old rubber plantation at RRIM Experimental Station Sg. Buloh, Malaysia.

Heavily grazed *Stenotaphrum secundatum* pasture.

Lightly grazed *Stenotaphrum secundatum* pasture.

Herded sheep grazing cover crops and natural vegetation in young rubber in Malaysia.

Use of cover crops in a young oil palm plantation.

Example of the new hedgerow rubber planting system.

Investigations into the nitrogen nutrition of *Paspalum notatum* in full sun, under a *Eucalyptus grandis* plantation and under shade cloth.

Arachis pintoi spreading beyond the evaluation plot - a new legume for plantations?

Opportunities for Integration of Ruminants in Plantation Crops of Southeast Asia and the Pacific

H.M. Shelton* and W.W. Stür*

Abstract

The advantages of raising livestock in conjunction with tree plantations include increased and diversified income, better use of scarce land resources, soil stabilisation and the potential for higher plantation crop yield through better weed control, nutrient cycling and nitrogen accretion. This paper provides an overview of the plantation and livestock industries in the Southeast Asian and Pacific regions and explores the opportunities for integration.

THE raising of livestock in conjunction with tropical plantation crops is a well established practice. The advantages of such dual use of land are documented and include: (a) increased and diversified income; (b) better use of scarce land resources; (c) soil stabilisation; and (d) potential for higher plantation crop yield through better weed control, nutrient recycling and nitrogen accretion.

The topic has attracted significant research and development activity in many countries. An extensive literature documents the potential for integration of pasture and livestock in plantation agriculture (Shelton et al. 1987). In this workshop, it is not our intention to repeat all these previous findings. Our objective is to present the results of some recent research and to review some past experiences, both successes and failures, with the extension of pasture technology to farmers. We believe that this will lead to a better understanding of forage–plantation systems and of the limitations to greater use of forages in plantation crops, and ultimately to improved adoption of new techniques.

The purpose of this paper is to provide an overview of the plantation and livestock industries in the Southeast Asian and the Pacific regions and to explore the opportunities for better integration of the two industries. This will provide a conceptual setting for the workshop.

Plantation Industries

The plantation crops to be reviewed are rubber *(Hevea brasiliensis)*, oil palm *(Elaeis guineensis)* and coconut *(Cocos nucifera)*. These crops play an important role in the economies of the countries of Southeast Asia and the South Pacific. While other crops have potential for integration with livestock (e.g. cashews and mangoes in Thailand, cloves and vanilla in Indonesia, and forestry in the Pacific), they are of lesser importance.

Regional production data show that, relative to the rest of the world, Southeast Asia is the major source of all three commodities (Table 1). Within Southeast Asia, Malaysia and Indonesia are the major producers of rubber and palm oil while the Philippines and Indonesia are the main producers of copra (Table 2).

Table 1. Productivity of plantation crops by region ('000 t) in 1987.

Region	Rubber (latex)	Coconut (copra)	Oil palm (oil)
Africa	266	207	1 526
North and Central America	13	223	138
South America	46	28	333
Southeast Asia	3 682	5 105	6 371
South Asia	360	1 468	–
Northeast Asia	202	–	200
South Pacific	1	409	158
World	4 574	7 440	8 727

Source: FAO (1988) and APCC (1987).

The South Pacific region is by world standards a minor producer of the crops (Table 1). However, relative to its population and economies, coconut production is a very important activity. Only Papua New Guinea produces significant quantities of palm oil (Table 2) and minor quantities of rubber latex.

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Trade in copra was the principal feature of the early development of many South Pacific countries and involved both subsistence smallholder and large-scale foreign-managed plantations. While the larger countries such as Papua New Guinea and Fiji have now diversified their economies, countries such as Western Samoa, Tonga, Cook Islands, Kiribati and Vanuatu are still dependent on the sale of copra for export income (Ward and Proctor 1980).

Table 2. Productivity of plantation crops ('000 t) in 1987 in Southeast Asia and the South Pacific.

	Rubber (latex)	Coconut (copra)	Oil palm (oil)
Southeast Asia	3682	5105	6371
Burma	15	–	–
Indonesia	1000	2200	1698
Malaysia	1580	197	4533
Philippines	150	2386	25
Thailand	860	205	115
Vietnam	57	109	–
South Pacific	–	409	158
Cook Islands	–	1	–
Fiji	–	13	–
French Polynesia	–	14	–
Kiribati	–	12	0
Marshall Is. and Micronesia	–	25	–
New Caledonia	–	1	–
Papua New Guinea	1	198	139
Western Samoa	–	34	–
Solomon Islands	–	47	19
Tonga	–	8	–
Vanuatu	–	53	0

Source: FAO (1988) and APCC (1987).

The production systems employed vary among crops and between regions and this may influence acceptance of forage improvement. The dominant mode of production of palm oil in Southeast Asia is from large estates, often over 1000 ha; these may be managed by government or private interests. Only in Malaysia and Thailand are there significant commercial independent smallholdings (Barlow 1985).

The system of production of rubber is different as approximately 82% of rubber plantations in Southeast Asia are managed by smallholders. These holdings are less than 25 ha compared with the average estate holdings in Indonesia and Malaysia of approximately 600 ha (Barlow 1983). However, a significant proportion of the Malaysian smallholdings are managed as large blocks in government-coordinated land development schemes. This has enabled the standards of management to be closer to that achieved by the large estates.

We have no precise figures on the proportions of smallholder and estate-managed coconut plantations. However, smallholder involvement is high.

The future prospects for the three plantation commodities is mixed. There is little doubt that the future international demand for fats and oils will rise substantially, and for this reason continued expansion of the area and production of palm oil is anticipated, particularly in countries such as Thailand (Barlow 1985). However, the actual result will depend on the availability and price of competing oils, especially soybean, and on the share of palm oil in the total supply of all other oils and fats (Barlow 1985).

As with palm oil, the future of rubber and potential for expansion will depend on movements in international demand and prices. Following many years of growth, production and consumption of natural rubber has remained relatively stable during the 1980s (Barlow 1983) although there has been a recent increase in demand (Anon. 1989). Increases in the productivity per unit area following adoption of improved technology and management can be expected, especially in the smallholder sectors of Indonesia and Thailand where farmers are becoming more commercially minded (Barlow 1983).

The history of coconut development in Southeast Asia and the South Pacific is similar to that of rubber and oil palm, in that international trade of the commodity commenced about 1850 (Purseglove 1972). In contrast to rubber and oil palm, there has been little expansion in the area planted to coconuts since World War II. As with the other crops, world demand fluctuates, but lower profitability compared to the other crops has dictated little recent expansion or uptake of improved varieties or management. Consequently, many coconut plantations now comprise ageing stands of lower-yielding palms, and managers are experiencing reduced productivity. There has also been a general thinning of stand density, especially in the Pacific region, where destructive cyclones have occurred. The future of coconuts is therefore less certain than the other two crops.

Ruminant Industries

Livestock numbers

Ruminant livestock have been a significant historical component of the agricultural sector in Southeast Asia where they are a source of meat for human consumption and of power for transport and agriculture. Current estimates of numbers show a majority of large ruminants in the region, especially cattle (28 million), with only Indonesia possessing significant numbers of small ruminants (18.2 million) (Table 3).

Table 3. Ruminant density ('000 head) in 1987 in Southeast Asia and the South Pacific.

Country	Cattle	Buffalo	Sheep	Goats
Southeast Asia	28 003	18 000	5 801	16 925
Burma	9 912	2 188	300	1 136
Indonesia	6 470	2 994	5 300	12 900
Malaysia	620	245	75	347
Philippines	1 695	2 857	30	2 027
Thailand	4 931	6 350	73	80
Vietnam	2 775	2 666	22	432
South Pacific	586	0	7	128
Cook Islands	–	–	–	3
Fiji	159	–	–	59
French Polynesia	7	–	2	3
Kiribati	–	–	–	–
Marshall Is. and Micronesia	12	–	–	4
New Caledonia	122	–	3	19
Papua New Guinea	123	–	2	17
Western Samoa	27	–	–	0
Solomon Isands	23	–	–	0
Tonga	8	–	–	11
Vanuatu	103	–	–	12

Source: FAO (1988).

Meat consumption projections for Southeast Asia point to a steadily increasing demand for meat which is likely significantly to outstrip production by the year 2000 when self-sufficiency may decline to 62%. This decline in self-sufficiency is expected despite a projected fourfold increase in the level of regional meat production (Remenyi and McWilliam 1986). Demand is being increased by rising living standards and a shift towards urban living.

In contrast to the Southeast Asian region, traditional subsistence animal production in the Pacific region is based on pigs and chickens. There is no tradition of ruminant animal production.

The first cattle, mainly dairy breeds, were introduced into the South Pacific region by missionaries in the late 19th century. Subsequently, cattle became important for weed control in coconut plantations managed by expatriates. World War II had a devastating effect on cattle numbers, particularly in Papua New Guinea and Solomon Islands, but numbers began to increase rapidly in these countries during the 1960s and 1970s with promotion and funding from local governments and international agencies (Shelton et al. 1986).

Total numbers of ruminants in the Pacific region are small by comparison with Southeast Asia, but nevertheless they are significant in terms of the local economies, especially in Fiji, Papua New Guinea, New Caledonia and Vanuatu (Table 3).

As for Southeast Asia, meat production does not meet local demand which is rising dramatically as incomes increase (Ward and Proctor 1980). An exception is Vanuatu, where a modest export industry is being developed.

The ownership patterns for livestock are quite different to those operating for the plantation crops. In Southeast Asia, ruminants are largely in the hands of smallholders. In the Pacific, the majority are held on larger estates, either government or privately owned.

The production systems of the two regions are also entirely different. In Southeast Asia, the proportion of permanent pasture relative to arable land and total livestock numbers is small (Table 4), necessitating high stocking rates and close integration of animals with cropping systems. Farmers therefore rely heavily on crop residues and communal grazing land for feed supply, but it is not normal practice to grow forages. Farmers in Southeast Asia, who have a long history of management of ruminants, keep animals for agricultural as well as for social reasons, and are often not completely commercial in their outlook. These factors have implications for acceptance of pasture improvement technology as will be discussed later in these Proceedings.

Table 4. Comparative agricultural land use ('000 ha) in some Southeast Asian and South Pacific countries in 1987.

Countries	Arable	Tree crops	Permament pasture	Forest
Burma	9 574	486	362	32 385
Indonesia	15 800	5 420	11 800	121 494
Malaysia	1 040	3 340	27	19 580
Philippines	4 530	3 400	1 200	10 950
Thailand	17 810	2 240	750	14 415
Vietnam	5 915	555	315	12 950
Total (ha)	54 669	15 441	14 454	211 774
(%)	18	5	5	71
Cook Islands	1	5	–	–
Fiji	152	88	60	1 185
French Polynesia	5	70	20	115
Kiribati	37	–	–	2
Marshall Is. and Micronesia	25	34	24	40
New Caledonia	10	10	277	708
Papua New Guinea	31	355	86	38 250
Western Samoa	55	67	1	134
Solomon Islands	40	17	39	2 560
Tonga	17	31	4	8
Vanuatu	20	125	25	16
Total (ha)	393	802	536	43 018
(%)	1	2	1	96

Source FAO (1988).

The Pacific countries with their small populations are relatively well endowed with land. Cattle are therefore grazed largely on permanent pastures, either naturalised or improved in a 24-hour grazing system. The larger holdings are managed as Western-style grazing ranches or integrated in coconut plantations. Almost all smallholder cattle are grazed under coconuts. The standards of animal husbandry vary greatly among both groups.

Prospects for Increased Integration of Ruminants in Plantation Crops

The trends towards higher ruminant populations and increased meat consumption will require a greatly increased forage supply. Remenyi and McWilliam (1986) suggested the need for a doubling of forage supply over the 15 years to the year 2000. One obvious source of naturally occurring forage and of land for improvement of forage supply is the area under plantation crops.

The potential benefits of integration of forages under plantation crops are well known and some have already been outlined. However, the suitability of the three crops for integration with ruminant production varies. Rubber and oil palm have shorter life cycles than coconuts and planting configurations of the former are such that the period of high light penetration to understorey vegetation is short. This has implications for the duration of forage supply, a topic that will be discussed during this workshop.

Nevertheless, in Malaysia, the arguments for greater integration of ruminants in rubber and oil palm plantations are persuasive. The country produces only 15% of mutton and 55% of beef supplies, and consumption is expected to increase to 12 500 and 50 000 million t respectively by the year 2000 (Wan Mohamed et al. 1987). The same authors suggest that current feed reserves including forages and by-products from plantation crops are capable of supporting more than 1 million cattle or 6 million sheep; and that the progressive plantation sector is sufficiently skilled to integrate livestock to take advantage of diversified income sources and reduced costs of chemical weed control.

Coconut plantations, especially those utilising traditional tall varieties, are more long-lived and more open in their structure, and therefore long-term ruminant production is sustainable.

Smallholder involvement in coconuts is also common so that opportunities for combining livestock under coconuts are more directly relevant to this sector, especially in the Pacific (Shelton et al. 1986). The need for diversified income is also greater with coconuts because of its lower profitability, especially as plantations age and productivity declines.

Intensive commercial ruminant production under plantation crops will require the sowing of productive high-quality forage species which are able to persist under grazing in shaded environments. While considerable progress has been made in the identification of suitable species, especially for coconuts (Reynolds 1988), we believe there is scope for further selection, among world forage germplasm collections, of improved genetic material suitable for the variety of environments that may be found under plantation crops. To improve our chances of success, we must increase our understanding of the biology of shade adaptation.

Improved forage supply is only one aspect of successful integration of ruminants and plantation crops. We also need to understand the animal production parameters of ruminants grazing in plantations so that new developments will be based on sound economic analysis from realistic estimates of productivity.

As research biologists interested in promoting rural development based on the adoption, by conservative producers, of new forages or perhaps even totally new production systems, we must not forget that many other socioeconomic factors may influence the decisions of farmers. Factors such as marketing infrastructure, land tenure, social attitudes, management expertise and availability of credit and information may have a critical influence.

We look forward to a full and open discussion of all of these issues during the workshop.

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The Environment and Potential Growth of Herbage under Plantations

J.R. Wilson* and M.M. Ludlow*

Abstract

Plantation agriculture is a significant contributor to the economy of many countries in Southeast Asia and the Pacific.

This paper examines the effects of the plantation canopy on the environment of the herbage understorey and its capacity for growth. A logical model which provides a basis for discussing plant adaptive changes to decreasing light levels is described. This model in a simplified form allows calculations to be made of the potential growth of grass or legume under various light levels; several examples are presented. Calculated growth rates of pasture are then compared with animal requirements to help assess, in the first instance, what animal production potentially can be supported. Finally, further research needs to provide inputs for this model are suggested.

The Environment

Radiation above the tree canopy

SHORT-WAVE solar (SW) radiation in the wet tropics varies with latitude and season mostly between 11 and 22 $MJ/m^2/day$, the average being about 17.2 (Cooper 1975). Horne (1988) found that mean monthly SW radiation at Ciawi in Indonesia (10°S) varied from as low as 9 $MJ/m^2/day$ in January to 17 $MJ/m^2/day$ in December, in most months falling between 13.5 and 17 $MJ/m^2/day$. Calculations from Chen and Bong (1983) for Serdang in Malaysia (4°N) give maximum values for clear days ranging from 22 $MJ/m^2/day$ in June to 27.1 $MJ/m^2/day$ in October. The latter compares with values as high as 32 $MJ/m^2/day$ in a subtropical environment in Brisbane, Australia (27°22'S). The cloudiness of the skies obviously greatly reduces the radiation incident on the plantation areas, and the mean monthly means of Horne (1988) are more realistic values for any calculations using SW radiation input.

While SW radiation (400–3000 nm, Jones 1985) has been most commonly measured by meteorological stations, it is photosynthetically active radiation (PAR) (400–700 nm) which is most relevant to plant growth. Currently the term photon irradiance (PI) is preferred to photon flux density or PAR, and is expressed in the units $\mu moles/m^2/sec.$ ($\mu E/m^2/sec$). PI can be calculated from SW radiation above the canopy using PI = 0.5 SW (Szeicz 1974), and $MJ/m^2/day$ can be converted to moles or Einsteins using 1M (1E) of natural daylight ≡ 0.23 MJ (Charles - Edwards 1982).

Radiation below the tree canopy

Quality of light

As sunlight passes through the tree canopy in plantations its quality is altered because the leaves preferentially absorb the light in the 400–700 nm wave band. Blue and red light are reduced compared with green and far-red (Holmes 1981).

Because light in the 400–700 nm wave band is preferentially absorbed by the tree canopy, the proportion of PI to SW incident on the herbaceous understorey may be substantially lower than for full sunlight. Baldocchi et al. (1984) measured a fall in ratio from 0.5 above an oak-hickory forest to 0.27 at the understorey level. Therefore, if SW sensors are used to determine the light available for growth of the understorey, the value will be greatly overestimated if the usual 0.5 ratio of PI to SW is used. We cannot say with certainty whether the ratio should be discounted to 0.27 for rubber, oil palm and coconuts because we

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are unaware of any measurements of this ratio under these tree canopies. The degree of attenuation of PI would probably vary between tree species, depending on the transmission properties of their leaves. Fortunately nowadays, with the common availability of instruments measuring PI directly, this factor rarely has to be taken into account.

Because of the differential absorption of red and far-red light, the ratio of red to far-red (R/FR) falls (Table 1). Such changes in this ratio can be directly measured with a special sensor (Skye Instruments, UK).

Table 1. Red/far-red ratios in full sun and under several plantation types. (Shelton and Wilson, unpublished data)

Full sun	Rubber Immature	Rubber Mature	Old coconut	Mature rainforest
1.20	1.07	0.62	1.03	0.43

These spectral changes, perceived by plants through the phytochrome system, may induce marked morphogenetic changes in the plants (Smith 1982). Stem elongation can be promoted (Child et al. 1981) and tillering and branching inhibited (Deregibus et al. 1985; Casal 1988; Thompson and Harper 1988). Work with tree seedlings in a controlled environment (Warrington et al. 1988) indicates the effect on stem elongation can be over and above that due to reduced light alone (Table 2).

It also appears that shade-intolerant species may show a greater stem elongation response to reduced R/FR than shade-tolerant species (Smith 1982). No information appears to be available for the tropical pasture species of interest for plantations.

Table 2. Effect of red/far-red ratio on stem length (mm) of three tree species (adapted from Warrington et al. 1988)

Tree species	High light	Low light		
R/FR	1.40	1.52	1.01	0.34
Pinus radiata	274	399	549	901
Agathis australis	1110	777	954	1232
Dacrydium cupressinum	496	286	443	466

Quantity of light

The changes in relative light transmission for rubber, oil palm, coconuts and eucalypts with age of plantation are summarised in Fig. 1. There are few data for young coconut and older eucalypt plantations. All four tree species show a rapid decline in light transmission over the first five years, reaching very low levels in rubber and oil palm. This rapid decline and the low minimum levels in the latter two species impose a severe restriction on pasture growth and survival, although there is some indication that light transmission increases to more moderate levels in old plantations. In coconuts, measured light transmissions in mature plantations range between 50 and 80%, which provide a reasonable environment for pasture growth. It is likely that eucalypts (used in the South Pacific islands) would be similar to coconuts in that light transmissions in mature plantations would be above 40%. The theoretical curve of Nelliat et al. (1974) for light transmission in coconuts, which is also shown in Fig. 1, has been reproduced in many publications. Comparison with actual measurements show it significantly overestimates the minimum light levels achieved, at least for the commonly used tall varieties of coconuts; possibly, it may reflect the situation in dwarf varieties.

A commonly used procedure for light transmission measurements has been to take a reading on a clear day at a single time (usually near noon) and at a single position (usually in the centre of a row). Such measurements may provide a useful general description for comparative purposes between various plantation situations. However, they are not very useful when actual light input is needed to enable a calculation of the potential for pasture production under the tree canopy. Such readings will usually overestimate the average daily light transmission received by the total pasture understorey over a period of time embracing a range of weather conditions giving both clear and cloudy days. When time of day and spatial variation have been taken into account, measurements by Sanchez (these Proceedings) indicate minimum light transmissions under rubber of about 4%, considerably lower than the minimum of about 10% indicated in Fig. 1. For modelling purposes the temporal and spatial variations under the canopy need to be integrated to give the average total daily PI input to the pasture area.

Light transmission of a canopy varies with the proportion of direct to diffuse light. Diffuse light penetrates better than direct light because it emanates from the whole hemisphere of the sky rather than from the point source of the sun. Therefore measurements taken on a clear day will underestimate transmission of light under the trees; this may be of special importance in the tropics because of the high incidence of cloudy weather resulting in a high proportion of diffuse radiation. The most precise measurements are obtained by integrating PI continuously over a period consisting of clear and cloudy days. If only instantaneous measures are possible, values should be obtained for both uniformly overcast and clear days.

Examples of the diurnal variation in light under a

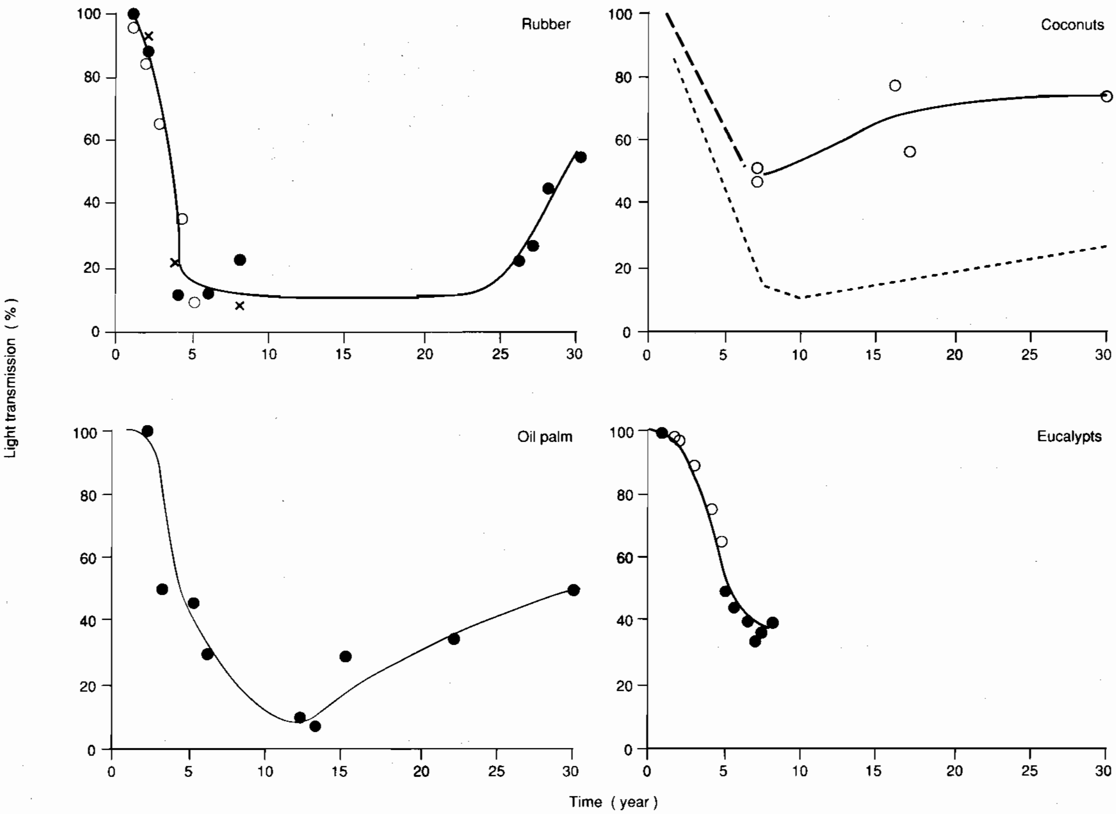

Fig. 1. Relative light transmission (%) profiles of photon irradiance with age for plantations of rubber (Chen 1989 [o]; Y.K. Chee and F.Md.A. Ahmad [x], unpublished data; J.P. Evenson [o], see Sophanodora 1989), oil palm (Chen 1989), coconuts (data summarised from Reynolds 1988 by H.M. Shelton, and theoretical curve [.....] by Nelliat et al. 1974), and eucalypts (*E. grandis* [o] Charles-Edwards, unpublished data; *E. deglupta* [o] Shelton et al. 1987b; the latter data was obtained using an integrating pyranometer measuring PI around midday).

tree canopy in a mid position between the tree rows are shown in Fig. 2. This can be expressed as relative PI transmission or as actual PI. The latter expression (Fig. 2b) is much more useful. Integration of the areas under the curves will give the average percentage of incoming radiation incident on the pasture over the whole day; it is seen from Fig. 2 that these values are lower than the peak transmission near midday. The area under the curve can also be used to calculate the average PI intensity over the day, and this then can be calculated to give a total PI input for the day. For example, for a 12-hour day and an average PI intensity of 1000 μmoles/m²/sec for the day, then PI input is

$(1000 \times 3600 \times 12) / 10^6 = 43.2$ Moles/m²/day
$43.2 \times 0.23 = 9.94$ MJ/m²/day

An example of spatial variation for 5.5-year-old oil palm (Chen and Bong 1983) measured near midday is given in Fig. 3. Transmission ranges from 73% in the middle of the interrow to 2.5% at the base of the stem. The area under this curve can be integrated to give an average relative light transmission to the pasture area over the whole interrow area under the trees (e.g. for the example in Fig. 3 the integrated value equals 47% of the light transmission measured at the centre of the row). Presuming the curve is not altered greatly with time of day, this information can be combined with the diurnal light input (from the central position between rows) to give an average daily light input over the whole pasture area. The problem is that few data sets are available to allow such calculations for many plantation ages and types.

The recent availability of small, inexpensive, hand-held integrating PI meters now enables the problem of spatial variability to be resolved more quickly and accurately. These instruments based on gallium arsenide phosphide photocells (Hamamatsu, Japan) are sensitive to the 300–680 nm range and can be

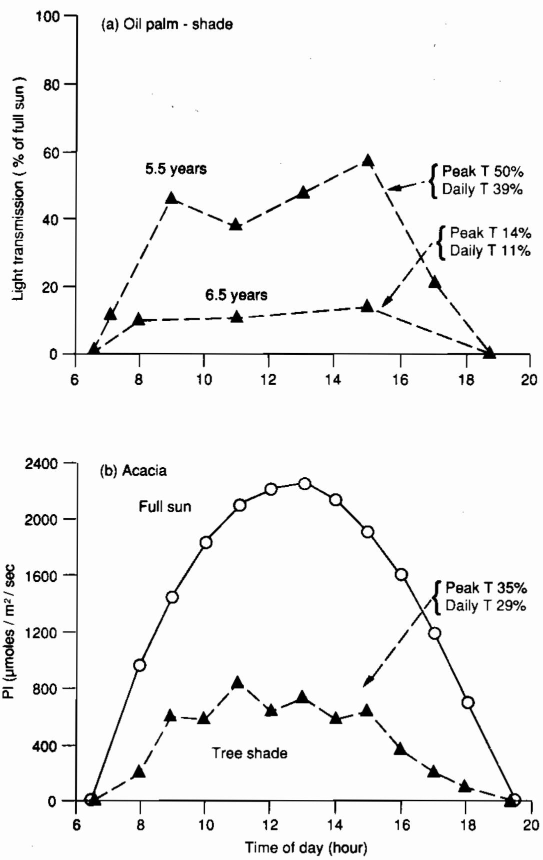

Fig. 2. Diurnal variation in light transmission for (a) oil palm – relative transmission of PI (%) under the canopy at two ages (adapted from Chen and Bong 1983, and (b) Acacia – PI above and under a canopy of 80% ground cover (from Ovalle and Avendano 1988). The area under the tree shade curves has been integrated to give the daily light transmission for comparison with the estimated peak transmission from a smooth curve fitted by eye to the points.

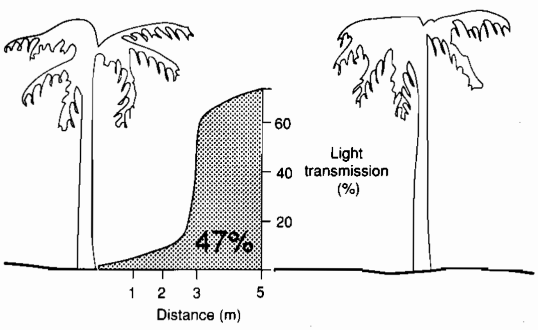

Fig. 3. Spatial variation in relative light transmission (%) in oil palm measured near midday (Chen and Bong 1983). The area under the curve has been integrated to give an average light transmission of 47%.

constructed of materials costing less than US$75. They can be programmed to integrate average PI over set time intervals, e.g. the operator can walk around within the plantation on a pattern to sample the spatial variation in light for, say, five minutes. Relative transmissions can be obtained using a second instrument operating outside the plantation at the same time.

Temperature under the tree canopy

The air temperature above the pasture under mature rubber trees is about 2–3°C lower at midday than above pasture in the full sun (Chen 1989). Ovalle and Avendano (1988) found air temperatures under an *Acacia* tree canopy to be 2–3°C lower for the maximum and 1.5–2°C higher for the minimum than in the open. Studies with artificial shade show a similar small difference (1–2°C) in maximum or minimum air temperature and in leaf temperature between these two environments (Wong and Wilson 1980). Soil temperatures can differ much more, and may be as much as 10°C lower under the tree canopy than in the open at the soil surface (Wilson and Wild 1990, these Proceedings) or 3–10°C at a depth of 2.5 cm (Ovalle and Avendano 1988). At lower depths, the differences are much smaller, about 1–2°C.

While the differences in air and leaf temperature are probably too small to have any important influence on pasture growth in a tropical environment, the substantial amelioration of surface soil temperatures by the tree canopy may be important for better seedling survival, soil water relations and possibly rate of litter breakdown and nitrogen mineralisation (Wilson and Wild, these Proceedings).

Humidity, evaporation and soil water under the tree canopy

Air relative humidity under the tree canopy is likely to be increased compared with that in the open or above the tree canopy; under artificial shade the maximum increase was about 6% (Wong and Wilson 1980; Wong et al. 1985a) over that in the open. Decreased radiation load under the shade of tree canopies should benefit the water relations of the pasture species. Leaf water potentials are higher in plants under shade than in full sun (Wong and Wilson 1980). Evaporative demand will be greatly reduced in the shaded environment, e.g. under acacia trees (Fig. 4a), and soil water availability for the pasture will be maintained at a higher level than in the open (Fig. 4b, and Wilson and Wild, these Proceedings) through the combined effects of less evaporation from the soil and lower transpiration rates of the pasture. These effects may lessen the periods when growth of pasture is restricted by soil water deficits during the dry season.

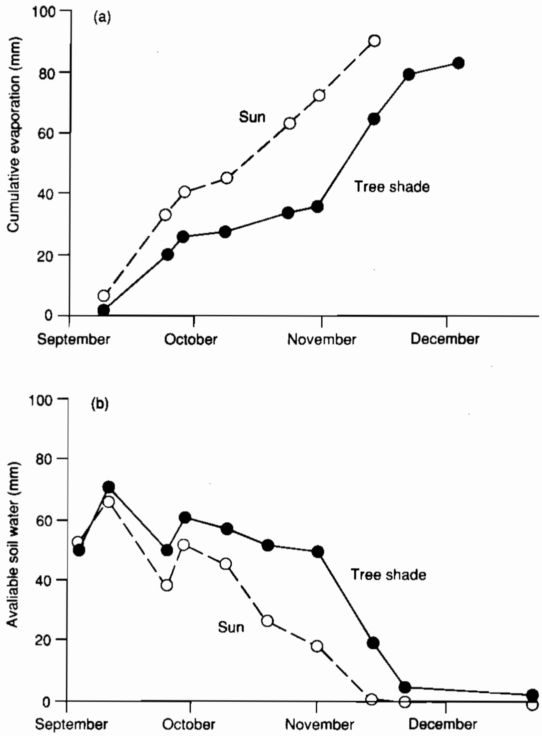

Fig. 4. Evaporation and available water content of the soil under the canopy of a plantation of *Acacia caven* (80% ground cover) and in the full sun (adapted from Ovalle and Avendano 1988).

However, the question of whether introduction of higher-performing pasture species into plantations to replace the natural vegetation will provide greater competition with the trees for soil moisture is unanswered at present. The review of coconut research by Reynolds (1988) suggests such an effect may be present in lower rainfall regions but not where annual rainfall exceeds 2000 mm. It is evident that this is an area which needs research to understand whether soil water changes under trees might lead to competition between understorey and tree, and reduced crop yield.

Growth Model

In considering plant response to shade and the constraints imposed on pasture performance by the reduced light under plantations, it is helpful to refer to a simplified growth model so that useful plant attributes might be assessed:

$$G = n E_w J - V \quad (1)$$

This model adapted from Charles-Edwards (1982) expresses rate of growth of above ground herbage (G) as a function of the partitioning coefficient for distribution of biomass to tops (n), the efficiency of light utilisation for photosynthetic accumulation into whole plant biomass (E_w), the amount of PI intercepted over a given time interval (J), and the loss of biomass (V) over the interval.

Because E_w is rarely, if ever, measured for pasture species this equation can be simplified to:

$$G = E J - V \quad (2)$$

where E is the efficiency of light utilisation for photosynthetic accumulation into above-ground herbage. The term E incorporates n and, as will be shown later, it can be determined directly from field experiments.

In a physiological sense E can be considered as:

$$E = (P - R) / J \quad (3)$$

where P is the mean gross rate of canopy photosynthesis and R is the mean dark respiration over the growth interval.

Partitioning coefficient (n)

Even though n need not be measured to use equation (2), it is discussed here because it can be greatly modified by shade and this has important implications for pasture regrowth and survival. A substantial increase in shoot to root ratio is a usual adaptive response to decreasing light in both grasses and legumes (Table 3), with variation between species in the extent of the response (Wong et al. 1985a,b; Samarakoon et al. 1990).

Selection for excessive adaptation in this characteristic could lead to difficulties where periodic severe water stresses occur and where grazing pressure is high. Plants may be susceptible to being pulled out of the ground, and regrowth might be limited because of reduced carbohydrate or mineral reserves in the crown and roots. Under full sunlight, recovery of growth after defoliation may be more dependent on residual leaf area than on stored reserves (Humphreys and Robinson 1966). Under shade this situation may be reversed, because other morphological responses to shade such as increased stem elongation and reduced branching may result in little leaf area and few axillary growing points remaining after grazing. Clements (1989) points out

Table 3. Change in shoot–root ratios of tropical grasses and legumes grown at different light levels. Data from 12 grasses and 14 legumes (adapted from Wong et al. 1985a,b)

Range for	100 ➔ 27% light	Relative increase
Grasses	2.5 ➔ 6.7	×2.8
Legumes	6.5 ➔ 14.3	×2.2

that the latter is a reason for poor tolerance to grazing of climbing and trailing tropical legumes even for pastures in full sun. This effect is likely to be exacerbated under shade. Carbohydrate reserves will thus be important for initiating new bud development. The capacity for accumulation of carbohydrate reserves in tropical pasture species is generally low, particularly for the grasses, because of their physiological characteristics (Wilson 1984), and this capacity is further diminished under shade (Wilson 1982). Therefore consideration perhaps should be given to those species of grasses and legumes with larger reserves of biomass in roots and/or rhizomes and stolons, which escape grazing. These species may be more tolerant of high grazing pressure (Wilson 1984), and they may be more persistent under dense shade than erect species that maximise leaf area production. However, prostrate species may have a more conservative growth performance under better light conditions. This seems to be borne out by the results of species testing given in this workshop. Stoloniferous species such as *Axonopus compressus*, *Brachiaria miliiformis*, *Paspalum conjugatum* and *Stenotaphrum secondatum* are reported to perform well in grazed pastures under shade (Rika et al. 1981; Watson and Whiteman 1981; McFarlane and Shelton 1986; Chen and Othman 1984). Prostrate legume species need to be evaluated in this context.

Radiation use efficiency (E)

This may be considered in relation to the light response curves for leaf or canopy photosynthesis and respiration, or measured empirically in the field from the relation of herbage yield to amount of intercepted PI. The former is considered first.

Photosynthetic rate (P)

The comparative light response curves for leaf photosynthesis of C4 tropical grasses and C3 tropical legumes is well known (Fig. 5a). The legumes become light saturated at low PI and thus P is relatively less affected by shade than in the grasses. However, light is not a determinant of photosynthetic efficiency until PI levels below about 200 µmoles/m^2/sec are reached. It is the slope of the tangent to the photosynthesis curve in this region that measures light use efficiency or quantum yield (CO_2 fixed/ unit absorbed PI). In warm environments at very low PI levels, the quantum yield of these two groups is relatively similar or slightly higher for C4 grasses than for C3 tropical legumes (Bjorkman 1981; Ludlow 1981). Thus, although C4 photosynthesis is decreased relatively more than C3 photosynthesis as light decreases, there is no reason to believe that C3 legumes will be inherently more efficient and have an advantage at low light levels. This view is sustained by ecological observations of species frequency in low light habitats

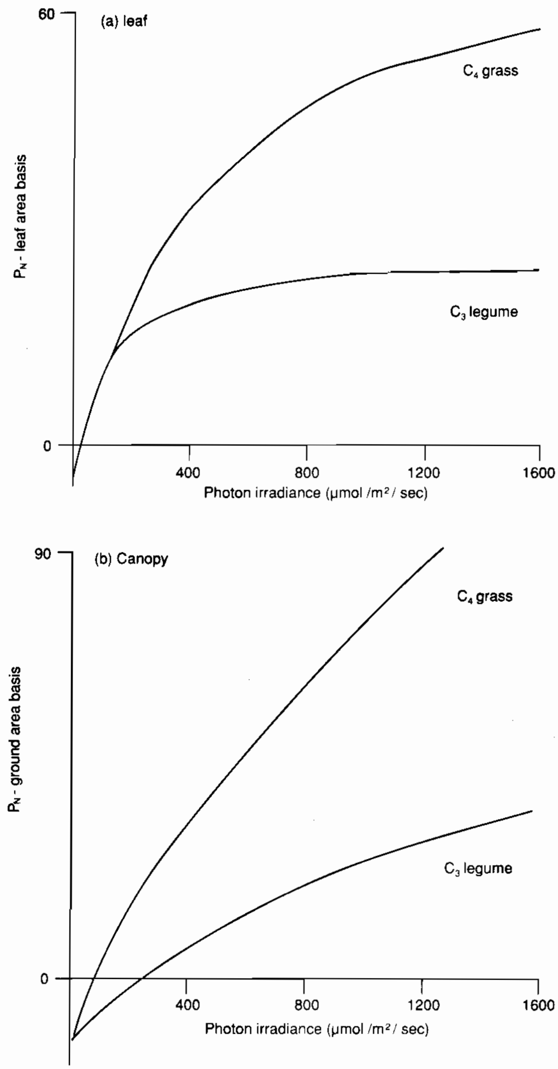

Fig. 5. Light response curves for net photosynthesis of a tropical C4 grass and tropical C3 legume for (a) individual leaf: *Pennisetum purpureum* and *Calopogonium mucunoides* (after Ludlow 1982), and (b) whole canopy: *Zea mays* (Alberda et al. 1977) and *Arachis hypogea* (Boote et al. 1980).

(Bjorkman 1976; Winter et al. 1982; Ehleringer and Pearcy 1983). Thus it appears that possession of the C4 photosynthetic pathway per se does not mean an inability to grow under heavily shaded conditions (Ludlow et al. 1974; Edwards et al. 1985). Competition for light appears to depend more on the leaves of a particular species gaining preferential access to the limiting factor (i.e. light) than on the photosynthetic response (Ludlow 1978).

It is a common viewpoint that 'sun-adapted' tropical grasses are at a photosynthetic disadvantage to their shade-adapted counterparts when grown under dense shade. This view is not correct as seen in the comparison of Ward and Woolhouse (1986) between the 'sun' species *Zea mays* and the 'shade' species *Paspalum conjugatum* (Fig. 6). Even though leaf P of *Z. mays* is greatly reduced when grown at lower light levels, its value is still equivalent to that of *P. conjugatum* at the lowest light value. In fact, it is the corollary that is most often true, that true shade-adapted plants are unable to adapt to high light with an increase in P. This may have two consequences. Firstly, their yield potential at high light is poor and thus they are not suitable species for planting in young plantations to take advantage of the high light levels available at that time. Secondly, some species are unable effectively to dissipate absorbed light energy through greater photosynthesis at high light. This results in damage to the photosystem and in leaf necrosis, and is termed photoinhibition (Bjorkman 1981).

Another aspect of photosynthetic light response that is not widely appreciated is the greater linearity of the response for both C4 and C3 species when P is measured for the whole canopy (Fig. 5b) or whole plant (Fig. 7) compared to individual leaves (Fig. 5a). Thus yield decline with lower light is likely to be closer to linear than would be thought from consideration of leaf response curves. The latter are very commonly measured but only a few sets of data are available for canopy P of tropical pasture species. These studies are mainly for canopies in full sunlight (e.g. Ludlow and Charles-Edwards 1980; Ludlow et al. 1982). The limited study of Sophanodora (1989) provides the only data found for shade-adapted pastures.

Respiration (R)

As light levels decrease in more shaded habitats, the rate of dark respiration also decreases. This is clearly shown in the data of Ludlow et al. (1974) for whole plants (Fig. 7). The decrease in R as a percentage of gross photosynthesis from 100% to 10% light was

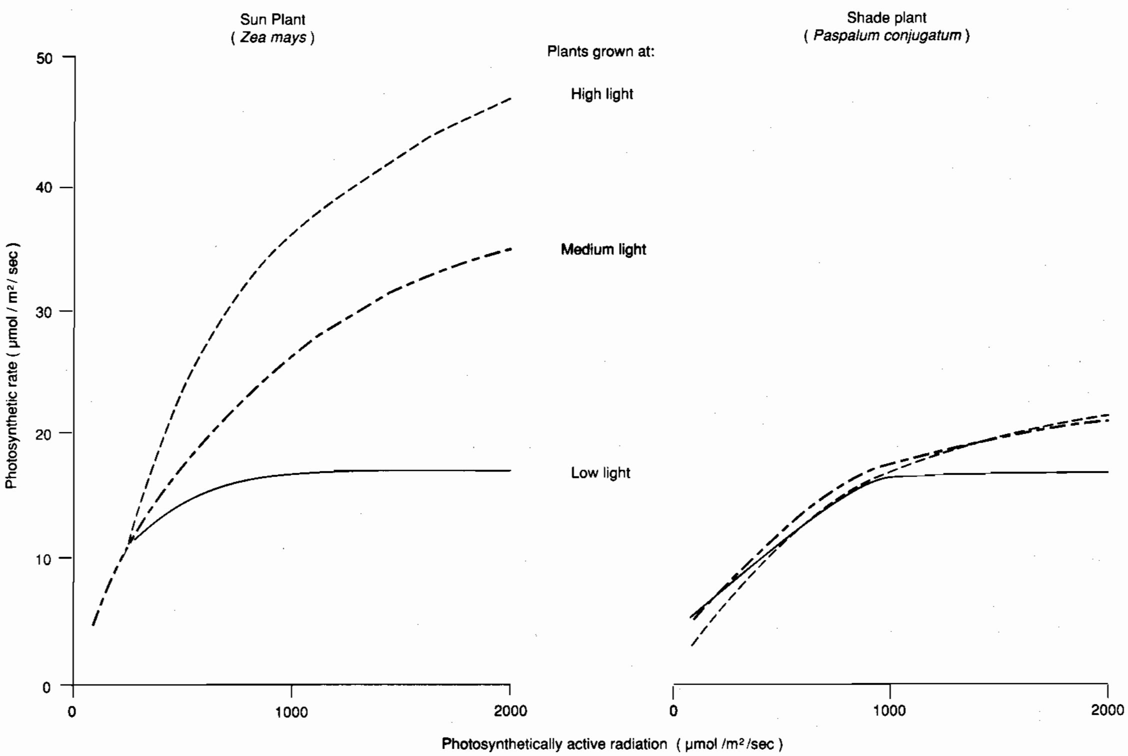

Fig. 6. Light response curves for leaf photosynthesis of a 'sun' plant (*Zea mays*) and a 'shade' plant (*Paspalum conjugatum*) grown at low, medium and high light levels (adapted from Ward and Woolhouse, 1986).

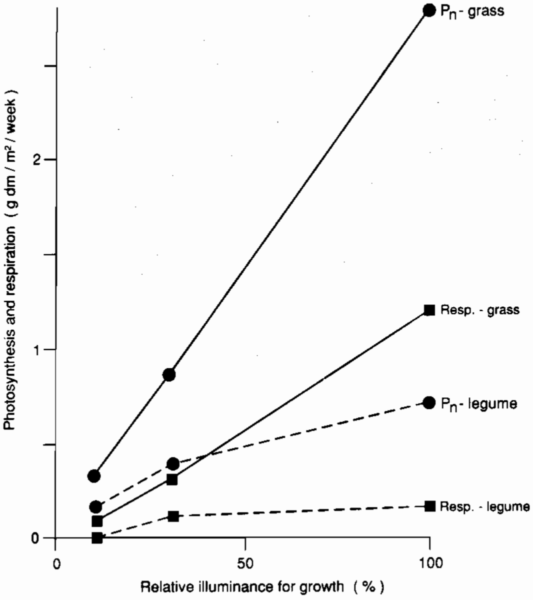

Fig. 7. Whole plant photosynthesis and respiration for a tropical grass (*Panicum maximum* var. *trichoglume*) and legume (*Macroptilium atropurpureum*) grown at different light levels (after Ludlow et al. 1974).

from 43% to 26% in *P. maximum* and from 22% to 20% in *Macroptilium atropurpureum*. The two tropical grasses studied in this work appeared to show a greater adjustment of R than the two tropical legumes studied. The decrease in R is of paramount importance for plants at very low light (e.g. <10% sunlight) so that they can maintain positive carbon balance (Bjorkman 1981; Winter et al. 1982). An important attribute of true shade plants is that they can reduce R to a very low level (Boardman 1977).

Reduction of R allows for a decrease in the light compensation point LCP i.e. when the rate of CO_2 fixation equals the rate of CO_2 respired. For example, for leaf of *Paspalum conjugatum*, a shade-tolerant species, LCP decreased from 34 µmoles PI/m^2/sec at high light to 10 µmoles PI/m^2/sec at very low light (Ward and Woolhouse 1986). In the same study, the decrease in LCP for the sun-species, *Zea mays*, was much less (25 to 16) and the LCP at low light of 16 µmoles/m^2/sec much higher than for the shade-species. Canopy P and R measurements of tropical pasture species after adaptation to various levels of shade are not available. They would be particularly valuable to allow calculation of the minimum PI necessary to maintain a positive carbon balance and hence the maximum percent age of shade at which some pasture growth could be expected. It should be remembered in such calculations for the tropics that photosynthesis occurs for only 12 hours a day and respiration for 24 hours. If photosynthetic light response curves of the form in Fig. 5b were available for shade-grown canopies then the average daily PI for light compensation on a 24-hour basis could be estimated from these plots by assuming the respiration component was doubled and plotting a new curve parallel to the experimentally derived curve and estimating the new compensation point at zero P (see diagrammatic illustration in Fig. 8).

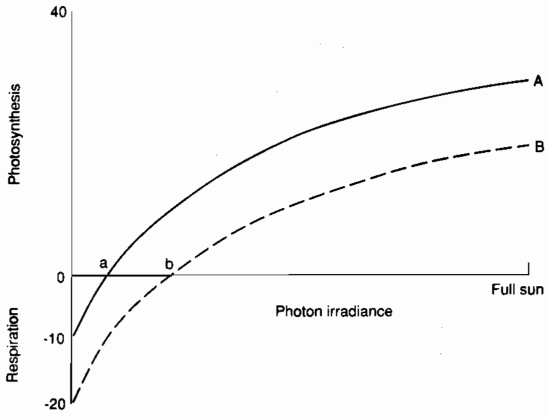

Fig. 8. Diagrammatic representation of the instantaneous photosynthetic light response curve of a shade-adapted pasture canopy (A) with light compensation point (a), and the adjusted curve (B) allowing for respiration 24 hours/day and photosynthesis for 12 hours. The value (b) is the average daily PI at which P is zero.

Direct estimation of E

Measurement of canopy P and R requires very expensive equipment available in few pasture research groups in the tropics. An empirical estimate of E integrating effects of P, R and n is more easily obtained from the slope of the linear relationship between herbage yield and accumulated intercepted PI (Fig. 9). Intercepted PI is measured using linear PI probes placed at ground level under the sward, and herbage yield determined by sequential harvesting. E is expressed as grams dry weight yield of herbage per unit of PI (g/MJ). The E value measured incorporates V (see equation (2)), i.e. refers to net biomass production. This procedure has been used often for crop species (e.g. Muchow 1985, 1989) but very few estimates are available for tropical pasture species, and as far as we are aware, only one set of data is available for pasture species under different light levels (viz. Sophanodora 1989). Some values for tropical crop and pasture grasses and legumes are given in Table 4.

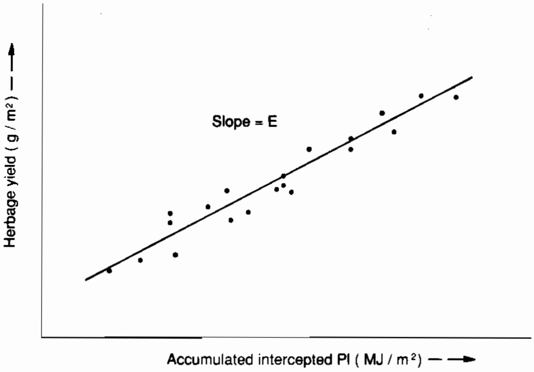

Fig. 9. Diagrammatic representation of the relationship between herbage DM yield and intercepted PI (based on Sophanodora 1989). Radiation use efficiency (E) is the linear slope.

Values of E for C4 grasses are substantially higher than for C3 legumes, and within each group there were some differences between species. Generally, these differences were less than those imposed by changes in growing conditions. Values were reduced under limitations of nutrients or water, and this would be expected from the decrease in P under these conditions. The most interesting effect from the point of view of pastures under plantations is that E increases substantially under lower light levels. Several features may explain this effect: more dry matter is partitioned to above-ground herbage (shoot to root ratio increases, see Table 3); leaf to stem ratio may increase (Table 5) thereby reducing light interception by less efficient stem tissue; leaf nitrogen concentration may increase (Samarakoon et al. 1990; Wilson and Wild, these Proceedings); and the leaves are less CO_2 - limited for photosynthesis.

These estimates of E are particularly useful for modelling potential pasture production under plantation systems, as will be discussed later. There is a need for more studies of tropical pasture under different shade levels to establish E values for some typical morphological types, e.g. examples of erect- and prostrate-growing sun and shade-tolerant species of grasses and legumes. If species differences are not large (as is suggested by data in Table 4) then such estimates could be widely applicable.

Amount of intercepted radiation (J)

To compensate for reduced light under tree canopies, plants attempt to maximise leaf area through an increase in shoot–root ratio (Table 3) and in leaf–stem ratio and/or specific leaf area (area per unit leaf weight) (Table 5; Samarakoon et al. 1990). The comparative data of Wong et al. (1985a,b), which are summarised in Tables 3 and 5 , and that of Ludlow et al. (1974) indicate that, in general, neither grass nor legume group could be considered more responsive than the other. However, there are substantial differences between species within the grass or legume group in morphological plasticity in response to shade, which possibly could be exploited in species selection.

The ability to regenerate leaf area after defoliation, and maximise J, is a most critical factor influencing pasture production even under full sunlight (e.g. Clements 1989). It is even more critical under shade, and the loss of sown, erect pasture species in plantation crops with time has been attributed as much to their inability to recover from repeated grazing as to their inability to tolerate shade per se (e.g. Chen and Ahmad 1983). The progressive decline in regrowth yields of erect-type legumes with successive defoliations under shade conditions is clearly shown by Wong et al. (1985b). Similar responses are evident for grasses, as shown in the species testing trials

Table 4. Estimates of radiation use efficiency (E, g/MJ of PI) for some tropical pasture and crop grasses and legumes under (a) different levels of light and nitrogen, and (b) water stress

Light and nitrogen[a]

Light level	Adequate N Guinea	Adequate N Signal	Adequate N Centro	Limited N Guinea	Limited N Signal
100% (full sun)	2.0	2.0	1.0	1.3	1.5
70%	2.5	2.3	1.0	1.4	1.6
30%	3.4	2.8	1.7	2.6	2.6

Water stress

	Maize[b]	Sorghum[b]	Millet[b]	Grain[c] legumes
Irrigated	2.4	2.1	1.9	1.4
Water stressed	1.6	1.9	1.8	1.1

[a] Sophanodora (1989): Guinea (*P. maximum*), signal (*Brachiaria decumbens*), centro (*Centrosema pubescens*)
[b] Muchow (1989): mean of 3 sowings
[c] Muchow (1985): mean of 7 types, range 1.2–1.6 (wet) and 0.8–1.2 (dry).

Table 5. Change in leaf–stem ratio and specific leaf area (cm^2/g) of tropical grasses and legumes with different light level; range for 12 grasses and 14 legumes (adapted from Wong et al. 1985a,b)

	Leaf–stem ratio: Range 100→ 27% light	Leaf–stem ratio: Relative increase	Specific leaf area: Range 100→ 27% light	Specific leaf area: Relative increase
Grasses	1.12→ 1.82	× 1.6	171→ 354	× 2.1
Legumes	1.24→ 1.21	×0	227→ 397	× 1.8

reported in this workshop. For most species, the adverse effects of shade will almost certainly be cumulative with successive grazings, so that for plants to survive non-grazing intervals must be lengthened as time and shading progresses. Species tolerant of close grazing will become particularly important under shade conditions, and the ability to retain some ungrazed leaf area may become vital to maintain J as high as possible.

While measurement of these morphological adaptations is relatively easy, incorporation of these changes into a model to predict their effect on J is somewhat more difficult. We believe a direct experimental measure of J is a more viable approach.

This can be done using linear PI probes placed above and below the sward. These can be connected to data loggers to record daily PI over any given time interval and thereby calculate per cent light interception (Muchow and Davis 1988). Alternatively, the probes can be measured manually at intervals over a day and the values integrated graphically to give a per cent light transmission for that day; this can be repeated at weekly intervals. Attention must be paid to keeping the probes free of dust and moisture condensation. The relative light interception values can then be plotted against time from defoliation. An example of such data (Sophanodora 1989) for guinea grass and centro grown at 30% light and defoliated at 8- or 4-week intervals is given in Fig. 10. The proportion of incident light intercepted over the regrowth period can be obtained by integrating the area under the curve (e.g. 68% for guinea grass defoliated 8-weekly (Fig. 10). This can be converted to an amount of PI ($MJ/m^2/day$) intercepted, and hence an estimate of J using the output from the probe above the sward.

These types of measurements are reasonably common for crops, but they are rare for tropical pastures. We are aware of only one set of data for tropical pasture species grown under different levels of shading (viz. Sophanodora 1989). There is a need for more studies with some characteristic examples of erect and prostrate grass and legume species. Also, Sophanodora's pastures had experienced only two (8-week cut) or four (4-week cut) cycles of defoliation. Since regrowth capacity is likely to decline with more defoliations, as discussed above there is need to

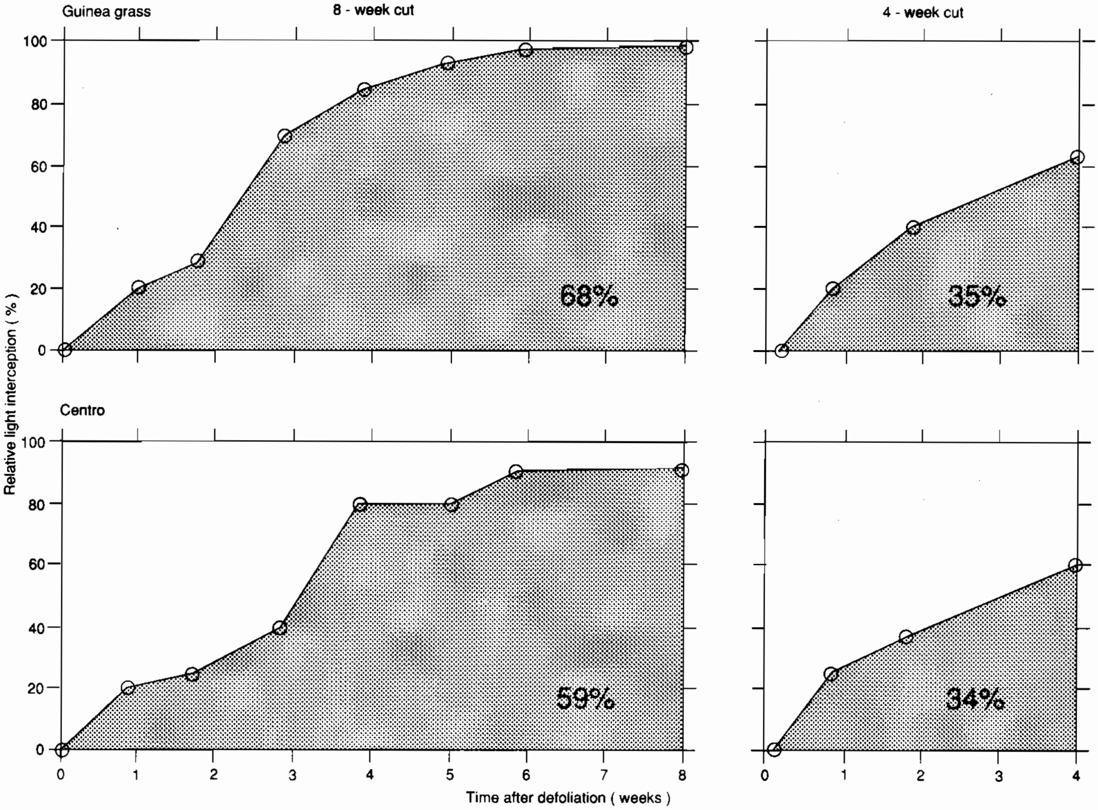

Fig. 10. Change in relative interception of PI with time for 8- and 4-weekly cut swards: guinea grass (*P. maximum*) grown at low to moderate nitrogen supply, and centro (*Centrosema pubescens*) (adapted from Sophanodora 1989).

examine pastures after a longer period of treatment to provide realistic estimates of J for older pastures under a plantation.

Loss of biomass (V)

This term may be particularly significant in pastures under older plantations. In these circumstances, standing biomass of understorey herbage may be only 500 kg/ha (Wan Mohamed 1977), and regrowth rates will be very low, so loss of leaf area through senescence, insect or fungal damage is of major importance. The wetter, more humid environment under the canopy of plantations increases the risk of fungal attack on the understorey species (Watson 1963; Grime 1966, 1981), and there is some evidence that shade-tolerant plants are more resistant to fungal infection than shade-intolerant plants (Grime 1966). Successful shade plants may develop defence mechanisms to reduce fungal or insect attack, and perhaps structural and other features that increase the natural longevity of their leaves. These adaptations could be counterproductive to their use as forage, because they may greatly reduce the palatability of the herbage to grazing animals.

There are no estimates of V which might be incorporated into models. Chen and Othman (1984) found that shade intolerant legumes (*C. pubescens, M. atropurpureum, Stylosanthes guianensis*) under 5–7-year-old oil palm, defoliated at long intervals of 8 or 12 months, had a lower accumulated yield over two years than when defoliated every 4 months, whereas this was not so for the shade-tolerant species, *C. caeruleum* and *D. ovalifolium*. This suggests that the latter may have had a lower loss of biomass in old swards.

Estimate of Pasture Growth Rate under Plantations

Such estimates can be made quite simply and should prove very useful in providing an assessment of potential grass or legume production under any particular light level. The potential for pasture production can then be compared with animal herbage requirements and the likelihood of sustaining a grazing capacity assessed for any particular age of plantation.

The growth model is simplified to:

$$G = E\,J \qquad (4)$$

where G is growth rate of herbage in g/m^2/day, E is radiation use efficiency in g/MJ of PI, and J is average amount of PI intercepted over any chosen time interval in MJ/m^2/day.

Two examples are worked through using data for incident light levels presented in the paper, and estimates of E and J for 8-weekly defoliated guinea grass and centro from Sophanodora (1989). The latter data are from experiments at Redland Bay, Brisbane, Australia on a krasnozem soil at low to moderate nitrogen fertility for the grass. The plantation light level is based on the diurnal variation given for a 6.5-year-old oil palm shown in Fig. 2a, and the spatial variation in Fig. 3.

Example 1: Guinea grass at low–moderate N level under oil palm with 14% light transmission at the row centre at midday.

i)	Daily SW radiation above trees (e.g. Ciawi, Indonesia)	16 MJ/m^2/day
ii)	Average daily light transmission % under trees at row centre (see diurnal integral, Fig. 2a)	11%
iii)	Average proportion of the above seen by pasture for whole interrow area (accounts for spatial variation, Fig. 3)	47%
iv)	Average daily SW incident on pasture ($16 \times 0.11 \times 0.47$) assuming that under trees, PI = 0.27SW	0.83MJ/m^2/day
v)	Average daily PI incident on pasture (0.83×0.27) (Assuming two-monthly regrowths intercept 68% of the incident PI (Fig. 10))	0.22 MJ/m^2/day
vi)	Amount PI intercepted for growth (0.22×0.68) assuming radiation use efficiency, E = 2.6 g/MJ (Table 4)	0.15 MJ/m^2/day
vii)	Average daily growth rate of herbage DM (0.15×2.6)	=0.39 g/m^2/day = 3.9 kg/ha/day
viii)	Assuming 250 growing days/year, yearly production herbage DM	= 975 kg/ha
ix)	Assuming actual area available for pasture under rubber is only 66% of total area, yearly production per ha of plantation	= 644 kg/ha
x)	Assuming 40% leaf (Sophanodora 1989), yearly production of leaf DM	= 258 kg/ha

Example 2: Centro under the same conditions as for guinea.

The following items will change:-

vi) Two-monthly regrowths intercept 59% of the incident PI (Fig. 10); vii) radiation use efficiency, E = 1.7 g/MJ (Table 4); and x) assume 49% leaf (Sophanodora 1989).

The calculations become:-

vii)	Average daily growth rate of herbage DM	= 0.22 g/m^2/day
		= 2.2 kg/ha/day
viii)	Yearly production herbage DM	= 550 kg/ha
ix)	Yearly production per ha of plantation	= 363 kg/ha
x)	Yearly production of leaf DM	= 145 kg/ha

Comments on the analysis

(a) The use of integrating PI meters as discussed in the text would allow the calculations to start at step (v). They would also avoid the difficulty of estimating the attenuation of PI relative to SW. In any case we are aware of no values for rubber, coconuts or oil palm.

(b) The estimate of proportion of incident PI intercepted will vary with the length of the regrowth interval considered (see Fig. 10). The value from Sophanodora (1989) was after only two defoliation cycles. Because it is expected that the regrowth will become slower with successive cycles, as discussed in the text, the values used in the analyses above probably substantially overestimate the proportion of PI intercepted in the regrowth of the old pastures, which would be present under the light level chosen. Thus the growth rates calculated represent the maximum potential to be achieved for a low to moderate nitrogen level. The E value will be higher for guinea at high nitrogen supply and light interception may also be higher.

(c) The number of growing days per year will vary from site to site, affected substantially by drought periods. Temperature should not be a limitation in most plantation areas.

(d) The area unavailable for pasture has been mentioned to be as high as 33% in rubber, and Reynolds (1988) mentions 12.5% for coconuts.

(e) Leaf DM available might be a better measure of potential for animal production than total pasture DM.

(f) The analysis takes no account of any loss of DM over the growth interval (i.e. V).

(g) The values for E come from Sophanodora (1989) and are for young pastures under shade; such high values may be difficult to sustain over periods of six months or more, and during flowering as opposed to vegetative growth stages.

Comparison of Potential Pasture Growth with Animal Requirement

Calculations of the maximum potential for pasture growth at any chosen light transmission (age of plantation) can be compared with animal requirement for production. Allowance should be made for the appropriate level of soil fertility.

Pasture feed requirement for cattle can be estimated using tables in Minson and McDonald (1987). An example is that of a 300 kg steer gaining at the low rate of 0.25 kg/head/day, which requires an intake of 5.8 kg/day of herbage at 55% digestibility. This requirement is much higher than the daily growth rate of total herbage on one ha of guinea (3.9 kg/day) or centro (2.2 kg/day) grown under low light in a plantation 5–6 years old. The feed deficit would be even greater if the animals are considered to consume mainly leaf.

Pasture feed requirement for sheep was estimated for a 15 kg lamb growing at 100 g/day, assuming the lamb received 100 g palm kernel cake per day and pasture digestibility was 60%. The estimate (B.W. Norton, pers. comm.) was 0.69 kg/day (4.6% of bodyweight). Another type of estimate from the experimental work in this ACIAR project (Tajuddin Ismail, Chong D. T. and Abd. Samat, pers. comm. is that a lamb gaining at the maximum rate of about 110 g/day requires 270 kg/ha of edible feed on offer.

Thus the estimates of potential pasture production may be compared with the estimated requirements of animals to estimate the carrying capacity of plantations of various light transmissions, and therefore assess potential viability of an animal enterprise.

Conclusions and Recommendations

This review highlights some of the problems associated with obtaining sustainable pasture production, and hence animal grazing, under the shade environment of plantation crops. The main environmental limitation is the reduction in photosynthetically active radiation (photon irradiance) incident on the pasture understorey. Whether competition for water between tree and pasture is a limitation for pasture growth is not known. However, by comparison with the situation in full sun, evaporation rate is reduced and soil water content is maintained at a higher level under the canopy of trees. Thus drought periods could be less severe under the tree environment. Air and leaf temperatures under trees differ little from those in the open, but soil surface temperatures can be much reduced. This may provide a more conducive environment for litter breakdown and nutrient turnover.

Most species of grass or legume adjust morphologically to compensate for increased shading as plantations grow. Generally, this is directed towards maximising the distribution of dry matter towards leaf area for light absorption. The inherent light use efficiency of these leaves for photosynthesis at low PI levels differs little between the C4 (grasses) and C3 (legumes) types. For undefoliated plants under dense shade, morphological adaptations, reduced respiration and preferential access of leaves to the light are probably the most important factors for success, as is possibly also the capacity to minimise leaf loss or damage. Under grazing, the morphological adaptations in some species towards taller plants and greater leaf production may reduce too far root reserves and the number of buds remaining after defoliation. This would greatly weaken the regrowth capacity of these species. Prostrate species with rhizome or stolon reserves and leaf area escaping grazing may be more successful. This aspect needs evaluation under grazing.

A simple growth model can predict potential pasture growth rate with only a few inputs, viz. PI incident on the pasture, radiation use efficiency (E) of the pasture, and the proportion of radiation intercepted over any regrowth period (J). These parameters can be derived experimentally without a large research input, but for all three there is need of more data.

PI on pasture under trees.

Records in the readily accessible published literature are scant even for the major plantation crops. Suitable PI instruments are now available to give values integrated over time and space to replace the present light/age curves largely obtained by single time-of-day measures at a single position (mid-row).

What is then needed are some mathematical functions to relate the integrated measures to the single measure, because the latter is very cost- and time-efficient. Armed with this information the operator can convert a centre-row noon transmission to a daily PI integral for use in the growth model.

Measures of E.

Very few values are available for tropical pasture species, especially for swards adapted to shade. It is suggested that some effort should be put into obtaining such values of E for some representative species of prostrate and erect grasses and legumes. Determinations at high and low nitrogen supply would help define the limits of the E values.

Measures of J.

These should be obtained from the same experiments as those determining E, using linear PI probes to determine light interception. The major qualification is that pastures should have been established for some time and be measured over at least 4-6 defoliation cycles to assess the cumulative effect of repeated defoliations under shade.

The above information will be extremely valuable in providing a predictive capacity to extend the usefulness of site-specific species testing. For a particular plantation crop giving a known range of shade levels, the viability of an animal enterprise can be assessed initially, without experiment, by comparing the predicted maximum potential for pasture growth with the proposed animal requirement for feed.

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Review of Forage Resources in Plantation Crops of Southeast Asia and the Pacific

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Abstract

Vast tracts of land in plantations in Southeast Asia and the Pacific sustain the growth of naturally occurring forages. The productivity of these forages under grazing is generally low, but most are persistent and well adapted to the local environmental and management conditions. No species is productive at light levels of less than 30% because of the limited production potential at low-light environments. In plantations with light transmissions of 30–50%, species such as *Axonopus compressus*, *Stenotaphrum secundatum*, *Ischaemum aristatum* and *Desmodium heterophyllum* are successful. At light levels higher than 50%, the more productive introduced species warrant consideration. A greater range of species is required which will persist and suppress weeds at moderate light intensities and low management levels.

A brief description of the principal species currently used for forage supply in plantation crops is given.

PLANTATION tree crops do not intercept all incoming light and consequently there is scope for the growth of natural vegetation or the cultivation of other useful introduced species.

From an animal production point of view, understorey natural vegetation can be divided into species which are eaten by ruminants and those which are unpalatable. In this context, the latter will be referred to as weeds while the 'eaten' species will be called forages. Undoubtedly, many plantation managers would use a different definition of the term weed.

The vast majority of available land in coconut, rubber and oil palm plantations is occupied by naturally occurring species. However, there are considerable areas of planted cover crops and very limited areas of planted forages.

This article describes the environment in which the three major plantation types (coconut, rubber and oil palm) occur, discusses the adaptation and value of the most frequently encountered naturally occurring and sown forage species, and reviews the potential for making best use of existing forage resources in plantation crops.

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Distribution and Habitat of Plantation Crops

The climatic and edaphic requirements of rubber and oil palm (Purseglove 1968, 1972) are somewhat similar, while coconut has different requirements (Table 1). Rubber and oil palm are grown mainly in the lowlands of the humid tropics, with high rainfall and no or only short dry seasons. While these crops can be grown on a wide range of soils they are usually found on acidic soils of low fertility.

Coconut, on the other hand, is grown chiefly along coastal belts in areas with an annual rainfall of 1300–2600 mm. Long dry periods are detrimental but can be tolerated where there is a good ground water supply. Long sunshine hours are required for high productivity. Coconut is grown on less acidic soils than rubber and oil palm, and is often found on alkaline and saline soils. The fertility of coconut soils varies from fertile volcanic soils to infertile coralline sands. The latter soils may be deficient in potassium (Macfarlane and Shelton 1986) and iron (Gutteridge 1978).

The root distribution of coconut and oil palm is similar with the majority of roots being concentrated within 2–3 m of the trunk (Purseglove 1972; Kushwah et al. 1973; Steel and Humphreys 1974), although some laterals occur. Roots of rubber are concentrated in the top soil layer with long laterals reaching into the interrows (Purseglove 1968).

The light environment under rubber and oil palm is similar with high initial light transmission at planting (>

Table 1. Distribution and habitat of plantation crops.

	Coconut	Rubber	Oil palm
Distribution	20°N – 20°S	15°N – 10°S	10°N – 10°S
Altitude (m)	< 300	Lowland	Lowland
Rainfall (mm/year)	1270 – 2550	> 1900	> 1800
Acceptable dry season	Short - medium	Short only	Short only
Required sunshine	Long	–	–
Humidity	High	Very high	–
Soil	Coastal belt (Wide range)	Wide range	Wide range
Soil pH range	5 – 8	4 – 8	4 – 6
Salinity	Tolerant	–	–
Required drainage	Excellent	Good	Adequate
Ground water supply	Required	–	–
Root distribution	Top 1.5 m, mainly within 2 m from trunk some laterals	Mainly top layer but long laterals 2 m from trunk	Top 15 cm, mainly within
Light transmission %*			
0 – 5 years	100 – 60	100 – 30	100 – 30
6 – 15 years	60 – 40	< 30	< 30
> 15 years	60 – 80	< 30	< 30

* estimation
Source: Purseglove 1968, 1972.

90%); this declines to very low levels (10–20%) within 6–7 years and remains low until the trees are replanted at an approximate age of 25 years. The majority of coconut stands in the world are of the tall variety, in which light transmission is high initially, declines to around 40% at age 5–15 years, and then increases up to 80% in old coconut stands aged 60 years and over (see Figure 1, Wilson and Ludlow, these Proceedings). Dwarf and hybrid varieties allow less light to penetrate their canopies and light levels are much lower.

Naturally Occurring Forage Resources

Many naturally occurring forage species are found in coconut, rubber and oil palm plantations in countries of Southeast Asia and the South Pacific. Some of the more important species are shown in Table 2. Both native and naturalised forages thought to have been present for many decades are included. Sown or planted species of more recent origin (some of which are now naturalised) are discussed in a later section.

Species which occur in all three plantation types, and in several countries, are *Axonopus compressus*, *Imperata cylindrica*, *Mimosa pudica* and *Paspalum conjugatum*. Their distribution includes both Southeast Asia and the South Pacific, which shows their ubiquitous nature and their ability to grow in a wide range of environmental conditions. Other species such as *Ottochloa nodosa*, *Mikania cordata* and *Asystasia* spp. are mentioned frequently in rubber and oil palm in Southeast Asia. There is also a large number of species observed under coconuts in the South Pacific some of which occur in Indonesia. Many of these may be adapted to the more alkaline coconut soils. The most widespread naturally occurring legume in natural vegetation in the South Pacific is *Desmodium heterophyllum* (Reynolds 1988).

The adaptation and value of the major naturally occurring forages are summarised in Table 3 (Bogdan 1977; Holm et al. 1977; Plucknett 1979; Steel et al. 1980; Macfarlane and Shelton 1986; Reynolds 1988). Some of these species are now discussed.

Axonopus compressus is renowned for its ability to withstand heavy grazing pressure and it has been reported to invade sown pastures which were not fertilised (Roberts 1970), which were overgrazed (Watson and Whiteman 1981), or where light levels were low (Chen et al. 1978). It is particularly valuable in heavily shaded situations (maybe less than 30% light transmission) where sown grasses cannot survive regular grazing (Reynolds 1988). Productivity of this grass is low and it is outyielded by more productive grasses in less heavily shaded areas, provided the level of management is sufficiently high to ensure persistence of the sown grasses (e.g. Smith and Whiteman 1983). It is well accepted by stock and produces moderate liveweight gains (Reynolds 1981), particularly if combined with naturally occurring legumes such as *Mimosa* spp. Nutritive value measurements indicate a high digestibility compared to *Pennisetum clandestinum* and *Stenotaphrum secundatum* (Samarakoon et al. 1990a).

Table 2. Natural vegetation occurring frequently in plantations.

Species	Coconut	Rubber	Oil palm
Grasses			
Axonopus compressus	Indonesia (11) Solomon Islands (1,9) Thailand (2) Vanuatu (6)	Malaysia (3,5,10)	
Brachiaria miliiformis	Indonesia (12)		
Brachiaria mutica		Malaysia (3)	
Chrysopogon orientalis	Thailand (2)		
Cyrtococcum oxyphyllum		Malaysia (5)	
Digitaria spp.	Indonesia (11,12)		
Eremochloa ciliaris	Thailand (2)		
Imperata cylindrica	Indonesia (11,12) Papua New Guinea (4) Thailand (2)	Malaysia (5,10)	Malaysia (8)
Microstegium ciliatum	Thailand (2)		
Otochloa nodosa	Thailand (2)	Malaysia (3,10)	Malaysia (8)
Paspalum conjugatum	Indonesia (12) Thailand (2) Papua New Guinea (4) Vanuatu (6) Solomon Islands (9)	Malaysia (3,10)	Malaysia (8)
Pennisetum polystachyon	Solomon Islands (9)		
Stenotaphrum secundatum	Vanuatu (6)		
Themeda australis	Solomon Islands (9)		
Legumes			
Calopogonium mucunoides	Solomon Islands (1,9) Papua New Guinea (4)		
Centrosema pubescens	Solomon Islands (1)		
Desmodium canum	Vanuatu (6)		
Desmodium heterophyllum	Indonesia (11)		
Desmodium ovalifolium	Thailand (2)		
Desmodium triflorum	Indonesia (11)		
Mimosa pudica and *M. invisa*	Solomon Islands (1,9) Vanuatu (6) Western Samoa (13)	Indonesia (12)	Malaysia (10)
Broadleaf species			
Asystasia spp.		Malaysia (3,7)	Malaysia (8)
Mikania cordata		Malaysia (5,10)	Malaysia (8)

Sources :- (1) Watson and Whiteman, 1981; (2) Manidol, 1983; (3) Ani Arope et al., 1985; (4) Hill, 1969; (5) Lee et al., 1978; (6) Macfarlane and Shelton, 1986; (7) Wong et al., 1989; (8) Chen and Othman, 1983; (9) Steel et al., 1980; (10) Wan Mohammed, 1978; (11) May, 1977; (12) Rika et al., 1981; (13) Reynolds, 1981; (14) Plucknett, 1979; (15) Holm et al., 1977; (16) Reynolds, 1988; and (17) Bogdan, 1977.

Paspalum conjugatum has a similar distribution to *A. compressus* but grows best on more acidic soils. While it can withstand moderate grazing it disappears under continuous high grazing pressure. In the South Pacific, it is less productive than *A. compressus* (Smith and Whiteman 1983). It is less readily accepted by stock than *A. compressus* and is generally regarded as a grass of low nutritive value.

Mimosa pudica is often regarded as a weed because of its spiny stems, but it is readily accepted by stock and high animal weight gains have been recorded (e.g. Partridge 1979; Reynolds 1981). It combines well with sward-forming grasses such as *A. compressus* and can withstand heavy grazing. Because of its spiny stems it is not usually recommended in sown pastures but it can form a useful component in naturally occurring swards (Reynolds 1988).

Desmodium heterophyllum is a perennial prostrate creeper which occurs throughout the South Pacific and Southeast Asia. Its success is related to its ability to withstand very heavy grazing pressure, and its shade tolerance (Reynolds 1988). While low-yielding, it can improve animal production when a component of grass pastures and is therefore a valuable component in any pasture. Except for coralline sands, it is adapted to a wide range of soils (Steel et al. 1980). Although a good seeder, mechanical harvest of seed is difficult and no commercial seed is available. However, it can be propagated vegetatively.

Imperata cylindrica is regarded as one of the worst weeds in the region (Holm et al. 1977), as it is often not readily accepted by stock. However, Falvey (1981) in a review of *I. cylindrica* concluded that it is underrated as a forage resource. It can support low rates of animal weight gain, particularly when grazed young or associated with a legume. It cannot withstand heavy grazing pressure and is seldom found in heavily shaded situations. Growth of this species is best on fertile soils but it is also found on poorer soils. Replacement with other more productive and nutritious grasses, particularly in intensive grazing systems, is generally recommended.

Ottochloa nodosa, Mikania cordata and *Asystasia* spp. occur frequently in rubber and oil palm plantations of Southeast Asia. All of these are readily eaten by stock (Ani Arope et al. 1985) and can contribute to animal production. A high feeding value has been reported for *Asystasia* spp. (Wong et al., 1989) and *M. cordata* (Ginting et al. 1987). All three species occur at varying light levels but are susceptible to regular grazing at low light levels. It is difficult to generalise on animal preference. For example, Pillai et al. (1985) found that the proportion of *A. intrusa* increased under sheep grazing in immature rubber while *O. nodosa* decreased. On the other hand, Rosley Abdullah (1985) observed that sheep grazed *A. intrusa* before *O. nodosa* and *M. cordata* in a slightly older rubber plantation.

Other herbaceous legumes which occur in some coconut areas include *Desmodium triflorum, Desmodium canum* and *Alysicarpus vaginalis*. Of these, *D. triflorum* is probably the most widespread legume but, because of its very low growth form and productivity, contributes little to animal production.

Sown or Planted Forage Species

There has been a long history of the use of legume cover crops in rubber, oil palm and, to a lesser extent, in coconut plantations. The planting of 'improved' forages for animal production has so far not been practised in rubber and oil palm except on an experimental basis, while there are some examples of commercial 'improved' pastures under mature coconuts.

Cover crops

Cover crops are planted to suppress weeds, control soil erosion and to add nitrogen to the plantation crop. Commonly used species are *Calopogonium mucunoides, Calopogonium caeruleum, Pueraria phaseoloides* and *Centrosema pubescens* (Plucknett 1979; Chee 1981). These are usually sown shortly after the planting of the plantation trees and dominate the interrow area for several years. As the light level decreases, naturally occurring species invade.

A summary of the adaptation and value of these cover crops as forages is presented in Table 3.

Chee (1981) described the succession of these covers when grown in combination and without grazing in young rubber. *Calopogonium mucunoides* dominates for the first year and then *Pueraria phaseoloides* in the second and third years. As light levels decrease further, *C. caeruleum* and *Centrosema pubescens* dominate and these latter two species will persist longer. When grazed by sheep, the proportion of *Calopogonium caeruleum* has been observed to increase while that of *P. phaseoloides* and *Centrosema pubescens* decreased (Pillai et al. 1985). This low acceptability of *Calopogonium caeruleum* has also been noted for cattle (Middleton and Mellor 1982). In a feeding trial with sheep and goats, Ginting et al. (1987) found that the digestibility of both *P. phaseoloides* and *C. caeruleum* was high, but the intake of *C. caeruleum* was low. A similar low intake by sheep of *C. mucunoides* has also been recorded (McSweeney and Wesley-Smith 1986).

Animal production from pastures containing *Centrosema pubescens* and *P. phaseoloides* has been excellent (Reynolds 1988). Both types require careful management to ensure persistence, a feature common to most twining, scrambling forage legumes. *Centrosema pubescens* can withstand moderate grazing pressure, while *P. phaseoloides* pastures can only be grazed lightly. *Calopogonium mucunoides* has persisted under moderate grazing pressure (cattle) under 60% light transmission coconuts in the Solomon Islands (Watson and Whiteman 1981).

Introduced forage species

Although many of the common 'improved' pasture species have been tried experimentally under coconuts, particularly in the South Pacific, only a few species are in commercial use.

The major problem encountered with many introduced forage species is lack of long-term persistence. There are many examples of excellent initial growth of highly productive species, but soon naturally occurring species (particularly unpalatable weeds) invade and the planted species disappear. There are, however, some examples of introduced species which have persisted for many years and which may be regarded as naturalised in some areas. These include *Stenotaphrum secundatum* and *Ischaemum aristatum* in the South Pacific and possibly *Brachiaria decumbens* in parts of Southeast

Table 3. Summary of adaptation of frequently occurring forages.

	Tolerance to shade	Forage yield	Animal product.	Required: Management level	Required: Soil fertility	Resistance to: Grazing	Resistance to: Drought	Resistance to: Soil acidity	Resistance to: Water logging	Resistance to: Weed invasion	Fertilizer response	Potential competition with plantation crops
Naturally occurring												
Axonopus compressus	H	L	M	L	L	H	L	H	M	M	M	L
Paspalum conjugatum	H	L	L	L	L	M	L	H	H	L	L	L
Imperata cylindrica	M	L	L	–	M	L	H	H	H	–	M	M
Mimosa pudica	H	L	M	L	L	H	–	–	–	–	–	L
Desmodium heterophyllum	H	M	H	L	L	H	H	M	H	–	–	L
Cover crops												
Calopogonium mucunoides	M	H	L	M	L	L	L	H	M	L	L	L
Calopogonium caeruleum	H	M	L	L	L	–	–	H	–	L	–	L
Pueraria phaseoloides	M	H	H	H	L	L	M	H	M	L	M	L
Centrosema pubescens	H	M	H	M	L	M	M	H	L	M	M	L
Sown or planted												
Stenotaphrum secundatum	H	M	M	L	M	H	–	–	M	H	–	L
Ischaemum aristatum	H	M	M	M	L	M	–	M	M	H	M	L
Brachiaria decumbens	M	H	H	M	M	M	M	M	M	M	H	M
Brachiaria humidicola	M	H	H	L	M	H	H	M	H	H	H	M
Panicum maximum	M	H	H	H	H	L	M	M	L	L	H	H

L = low, M = moderate, H = high

Asia although this latter species has not persisted in coconut plantations of the South Pacific. The most successful sown forages have been included in the agronomic summary in Table 3. Apart from being well adapted to the environmental conditions, these species keep out weeds and can withstand quite high grazing pressures.

As far as legumes are concerned, there are few examples of successful species. *Desmodium heterophyllum* and *Centrosema pubescens* are probably the most widely used herbaceous species. There are also some tree legumes such as *Leucaena leucocephala* and *Gliricidia sepium* which are persistent and highly productive under older coconuts. The most successful introduced species are now discussed.

Stenotaphrum secundatum is a low-growing stoloniferous grass which was planted in Vanuatu more than 40 years ago and, at low light levels, is considered more productive than *Axonopus compressus* or *Paspalum conjugatum* (Macfarlane and Shelton 1986). Its vigorous growth habit ensures relatively weed-free swards even at high grazing pressure but it combines with herbaceous legumes such as *D. canum, Mimosa pudica* and *Vigna hosei* at lower stocking rates. Animal production from pure *S. secundatum* pastures is low but can be expected to improve when combined with herbaceous or tree legumes (Macfarlane and Shelton 1986). *Stenotaphrum secundatum* is easily propagated vegetatively but produces no or little viable seed. The digestibility and intake of *S. secundatum* is similar to *P. clandestinum* (Samarakoon et al. 1990b) and it appears to be an accumulator of sodium (Macfarlane and Shelton 1986).

Ischaemum aristatum is a low-growing, stoloniferous grass which has a higher yield than *S. secundatum* at light transmission levels of greater than 40%. It tolerates high grazing pressure and moderate liveweight gains have been reported (Reynolds 1988). It combines well with herbaceous legumes such as *D. heterophyllum* and *Centrosema pubescens*. It is established from cuttings and can be grown on infertile and fertile soils of medium to heavy texture (Steel et al. 1980). At higher light levels (>70%), other grasses such as *Brachiaria decumbens* are capable of producing higher animal production.

Brachiaria decumbens, a medium-height stoloniferous grass, is capable of producing very high dry matter yield at light levels of more than 70%, when grown on moderately fertile soils (Reynolds 1988). It can withstand heavy grazing pressure and produce high liveweight gains, particularly when mixed with legumes. Because of its vigorous growth habit it is difficult to maintain herbaceous legumes with this grass, especially at high grazing pressures (Macfarlane and Shelton 1986). It can be established from seed or vegetatively, but vegetative propagation is more difficult than for *S. secundatum* or *I. aristatum*.

Brachiaria humidicola is a strongly stoloniferous grass with an adaptation similar to *B. decumbens*, but it does particularly well on alkaline coralline soils (Macfarlane and Shelton 1986). It can withstand a higher stocking pressure than *B. decumbens* and, although less readily accepted by cattle, it has been reported to produce reasonable liveweight gains (Reynolds 1988). As with *B. decumbens*, a major difficulty is the maintenance of companion herbaceous legumes. On the other hand, its vigorous habit suppresses weed growth. This species is widely used in Fiji and can be propagated easily by cuttings.

Panicum maximum cultivars have been used for grazing under coconuts in some areas. Plucknett (1979) considered the cultivars Petrie (Green Panic) and Embu (Creeping Guinea) to be the two most promising cultivars. These grasses combine well with legumes and produce excellent liveweight gains (Macfarlane and Shelton 1986). However, careful management including moderate grazing pressure and regular fertilisation is also required. Overgrazing or lack of fertilizer leads to weed invasion and the loss of the sown grasses.

Other grasses which are used to some extent under coconuts are *Brachiaria miliiformis* and *B. mutica*. The popularity of the latter species is related to its ease of establishment from cuttings, and its high yield and quality. However, it is not shade-tolerant and suitable only in very old coconut plantations in wetter areas (Reynolds 1988). *Brachiaria miliiformis* is used extensively in Sri Lanka but has been prone to disease attack in the more humid tropics (Reynolds 1988). It has been reported to be more shade-tolerant than other *Brachiaria* spp.

The legumes *Centrosema pubescens, Desmodium heterophyllum, Pueararia phaseoloides* and *Calopogonium mucunoides* have been described already. Other herbaceous legumes used to some extent include *Macroptilium atropurpureum, Desmodium intortum* and *Neotonia wightii*. All of these require careful management and will not persist when overgrazed.

Leucaena leucocephala and, to a lesser extent, *Gliricidia sepium* are used as a feed supplement to grazed pastures under coconuts. The prospects of *L. leucocephala* have diminished with the arrival of the leucaena psyllid but tree legumes in general have excellent prospects for integration into plantation systems. Their main advantage is their persistence, even under heavy grazing, where it is often difficult to maintain herbaceous legumes.

Conclusions

There is quite a range of species naturalised under the various environmental regimes of plantation crops. However, no species can be recommended for light levels of less than 30% because of the limited production potential of very low-light environments. In plantations with light transmissions of 30–50%, species such as *Axonopus compressus, Stenotaphrum secundatum, Ischaemum aristatum* and *Desmodium heterophyllum* may be suitable. Only when light levels are higher than 50% do more productive species warrant consideration.

At low management levels (high stocking pressure, no fertilizer, etc.), persistence and suppression of weeds usually requires an aggressive grass such as *Stenotaphrum secundatum*. Unfortunately, the ability to suppress weed growth usually means incompatibility with most useful herbaceous legumes. The most successful herbaceous legumes for combining with aggressive grasses are *Desmodium heterophyllum* and *D. triflorum*. Tree legumes may also play an important role in improving the feeding value of such pastures. Under higher levels of management, excellent levels of animal production can be achieved with highly productive sown grass/legume swards, particularly at light levels of 70% and above.

Despite the plethora of naturally occurring species available for reduced light situations, a greater range of grasses and legumes is required which will persist and contribute to annual production in low management and input systems.

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Forage Resources in Malaysian Rubber Estates

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Abstract

A survey of forage resources was undertaken in three age groups of rubber (1–2, 3–5 and 6–10 years) in five estates in the central region of Malaysia. Standing forage dry matter declined from 2600 kg/ha in young rubber to just over 500 kg/ha in mature plantations. Botanical composition varied with age of rubber and therefore light transmission. *Pueraria phaseoloides* was the dominant species in the interrows during the first 1–2 years. In 3-5 years old rubber the dominant plant species were the volunteer grass *Ottochloa nodosa* and the planted legume *Calopogonium caeruleum*. In 6–10 year old rubber ferns made up nearly 50% of the vegetation but volunteer grasses also contributed to the total biomass.

The Botanal method of sampling used in this study permitted the recording of larger numbers of samples in the field for yield and botanical composition than was possible using conventional systems of cutting and weighing quadrats.

IN Malaysia, the area planted with rubber is estimated at 1.86 million ha (RRIM 1988). This vast cultivated area has tremendous potential for integration with livestock. To date sheep have proven to be very successful because their husbandry is sound economically and there is no requirement to clear new land purely for the purpose of growing pastures for animal production. The system maximises the use of agricultural land, provides returns from the sale of animals, and reduces the use of herbicides and the cost of weed control.

The amount and quality of forage resources have been shown to be important factors in sheep production under perennial crops of rubber and oil palm. Chen et al. (1978) reported that there were up to 60 different plant species in plantations, and 70% of these have been reported to be palatable to livestock (Wan Mohamed 1978). The age of the tree crops has a marked influence on the botanical composition and yield of forage (Wan Mohamed 1978, Chen and Othman, 1983). They reported a rapid decline in legume composition (except *Calopogonium caeruleum*) with age, and legume species accounted for less than 20% of the total dry matter yield when the tree crops were more than three years old. The standing dry matter biomass under rubber declined rapidly from 1600 kg/ha during the first two years to less than 600 kg/ha when the trees were 3–3.5 years old. These forage yields were much lower than those reported earlier by Mahyuddin et al. (1978) and Devendra (1982) and need further verification under the variable agro-management, climatic and soil conditions that can be found under the plantations of Malaysia. There is also a need for an appropriate survey methodology which can be used to quantify the forage resources under rubber. These data can then be used as base data for the estimation of the sheep production potential under rubber.

This study reports the results of a survey of factors influencing forage yield and composition in the rubber plantations of the central region of Malaysia.

Materials and Methods

The survey method adopted in this study of forage yield and botanical composition was a modified version of the Botanal method (Jones and Tothill 1985). Five rubber estates in the central region of Malaysia which did not raise sheep were selected for the survey. The estates were Sg. Rinching, Sg. Chinoh, Galloway, Bradwall and Sg. Jernih. At each site, the survey was conducted for 3 age groups of rubber: 1 – 2 years, 3 – 5 years and 6 – 10 years. Initially, a general view of the fields was obtained with the aid of field maps and the staff of the estates. A representative site was then selected. The survey was carried out with a series of 6 – 8 quadrats (1.0 × 0.5 m) taken across the rubber interrows in a band pattern. The bands were chosen every 10 trees in a systematic grid pattern. In each quadrat, the botanical composition was visually estimated and the relative yield was ranked between 1 and 10, based on

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the Botanal method where 1 = lowest yield, 5 = medium yield and 10 = highest yield. This ranking system was calibrated against quadrats which served as references and were subsequently cut at 2 cm above ground level, dried and weighed. Three recorders were involved who independently scored each quadrat. A total of 30 bands were ranked by each recorder. After sampling the field, each recorder cut a total of 20 samples to determine the relationship between yield and individual Botanal ranking. For each rubber age group, photosynthetically active radiation (PAR) readings were taken to determine the light transmission under the rubber trees. These readings were taken with two integrating PAR recorders, one outside the plantation in full light while the second was moved in a systematic pattern through the plantation. Integrated readings were taken over a 10-minute period between 1000 and 1400 hours.

Site Description

The soil texture of the estates is as follows: Sg. Rinching (clay), Sg. Chenoh (clay/laterite), Galloway (clay/sandy clay), Broadwall (clay/laterite), and Sg. Jernih (clay, quartzite/laterite). The rubber clones were Sg. Rinching (RRIM 600, PB 235, 314 and 340), Sg. Chenoh (PB 260, 310 and 314), Galloway (PB 312, 235 and 260), Bradwall (PB 217, 260, 310, 311 338 and RRIM 600), Sg. Jernih (PB 255, 260 and RRIM 600). The planting distances between the rows varied from 6.3 × 2.7 m to 3.0 × 8.0 m for 1–2 years old rubber, 4.2 × 4.2 m to 5.7 × 4.1 m for – 5 years old rubber, and 3.7 × 4.8 m to 4.0 × 8.1 m for 6-10 years old rubber. At these planting distances, the number of plants/ha for 1–2, 3–5 and 6–10 years old rubber were 417–588, 428–567 and 309–563, respectively. The mean girth of rubber trees at 127 cm above ground level for 1–2, 3-5 and 6–10 years old rubber was 8.4, 35.4 and 63.5 cm, respectively. Mean legume seeding rates planted in the interrows were 3.6 kg/ha of *Pueraria phaseoloides*, 1.6 kg/ha of *Calopogonium mucunoides*, 0.5 kg/ha of *Centrosema pubescens* and 0.6 kg/ha of *Calopogonium caeruleum*. The average annual rainfall varied from 1566 to 4232 mm/year.

Results and Discussion

Forage yield

The mean standing dry matter yield of forage (kg/ha) and PAR values in the interrows of the three age groups of rubber in the five estates are given in Tables 1 and 2 respectively.

The mean yield of forage was highest (2602 kg/ha) for 1–2 years old rubber while the lowest yield (537.5 kg/ha) was recorded for the 6–10 years old rubber.

The low yield under the 6–10 years old rubber was due to the closure of the canopy and the reduced light transmitted to the interrows. This was confirmed by the light transmission data which was 92% for 1–2 years old rubber and only 9% for 6–10 years old rubber. Forage yields obtained in this study were higher than the yields reported by Wan Mohamed (1978) for all age groups. The amount of forage

Table 1. Standing forage dry matter yield (kg/ha) in three different age groups of rubber.

Age of rubber (years)	Estates					Mean	S.E.
	Sg. Rinching	Sg. Chinoh	Galloway	Bradwall	Sg. Jernih		
1 – 2	3250	2493	2974	2323	1970	2602	228
3 – 5	2080	995	1187	1032	940	1247	212
6 – 10	700	694	432	324	470	524	95

Table 2. Photosynthetically active radiation (%) in three different age groups of rubber.

Age of rubber (years)	Estates					Mean	S.E.
	Sg. Rinching	Sg. Chinoh	Galloway	Bradwall	Sg. Jernih		
1 - 2	85	89	93	94	99	92	1.4
3 - 5	31	27	16	15	19	21	1.7
6 - 10	14	8	6	9	12	10	0.9

present in the different age groups of rubber will determine the potential stocking rate per unit area under rubber. However, it must be emphasised that these yields are of standing biomass only and do not reflect the potential yield of regularly defoliated herbage which would be higher in young rubber.

Forage composition

Details of the forage composition for the three age groups of rubber are given in Table 3. The main forage species in the 1–2 years old rubber, where light transmission was highest, were legumes, with only some grasses. The main species were the planted cover crops *Pueraria phaseoloides* (79%), the volunteer grass *Ottochloa nodosa* (7%), and *Paspalum conjugatum* (6%). In the second age group (3–5 years), the composition of forage species had changed and the proportion of the previously dominant legumes had declined, while the proportion of grasses and broadleafed species had increased. The main forage species in this age group were *Ottochloa nodosa* (28%) and *Calopogonium caeruleum* (25%). *Aystaysia intrusa* (11%) was dominant in one of the estates only. In the oldest age group (6–10 years), where the light transmission was low, the composition had further changed to broadleafed plants and grasses. The dominant plant species were ferns (41%), and the grass *Ottochloa nodosa* (20%). These forage species are known to be relatively shade-tolerant.

In the 1–2 years rubber, the legume *Pueraria phaseoloides* was the dominant species partly because the interrows of the five surveyed sites were sown with high seeding rates of this species (3.65 kg/ha). The *Pueraria phaseoloides* composition decreased quickly from 79% to 12% and 1% for 1–2, 3–5 and 6–10 year groups respectively. This was probably related to the decreasing light transmission due to the closure of the canopy as the rubber matured.

The more shade-tolerant *Calopogonium caeruleum* became the dominant legume species. The composition of *Calopogonium caeruleum* in the 3–5 year group was 25% while for the 6–10 years old was only 9%. The increase in the content of volunteer grasses and broadleafed species, as the canopy closed, was shown earlier by Wan Mohamed (1978). In mature rubber only shade-tolerant species were found and ferns dominated.

Table 3. Forage composition (%) in three different age groups of rubber

Age of rubber (years)	Location (estates)	Grasses			Legumes		Broadleafed Species		
		Co	On	Pc	Cc	Pp	Asy	Mc	Fer
1 – 2	Sg. Rinching	0	9	15	0	75	0	0	0
	Sg. Chinoh	1	14	12	0	68	1	1	0
	Galloway	0	3	2	0	94	1	0	0
	Bradwall	1	5	0	1	77	1	0	0
	Sg. Jernih	0	5	1	0	80	1	3	0
Mean		1	7	6	0	79	1	1	0
3 – 5	Sg. Rinching	0	16	5	33	3	10	21	1
	Sg. Chinoh	0	48	0	34	1	0	3	1
	Galloway	0	35	2	0	46	0	15	0
	Bradwall	3	18	4	4	10	5	4	0
	Sg. Jernih	2	22	2	7	2	39	12	13
Mean		1	28	2	25	12	11	11	3
6 – 10	Sg. Rinching	45	17	8	8	0	2	4	11
	Sg. Chinoh	2	36	2	22	0	0	2	27
	Galloway	9	44	6	2	6	19	1	2
	Bradwall	0	0	0	13	0	0	0	87
	Sg. Jernih	3	1	8	0	1	0	1	80
Mean		12	20	5	9	1	4	1	41

Asy = *Asystasia intrusa*
Cc = *Calopogonium caeruleum*
Co = *Cyrtococcum oxyphyllum*
Fer = Ferns
Mc = *Mikania micrantha*
On = *Ottochloa nodosa*
Pc = *Paspalum conjugatum*
Pp = *Pueraria phaseoloides*

Note: Minor species not included in Table.

Botanal method

The correlation coefficients between the Botanal ranking scores and forage dry weight in the three rubber age groups were highly significant. The Botanal visual ranking method was therefore appropriate for the determination of forage yield under rubber. The experience obtained in using the method can be adopted in the survey of forage resources in other perennial tree crops.

Conclusion

The study of the forage resources under three age groups of rubber (1–2 years, 3–5 years and 6–10 years) in five estates in the central region of Malaysia has quantified the standing biomass yields of forages under different light transmissions. The amount of forages available will determine the stocking rate per unit area at the different ages of rubber that can be sustained.

There was a succession of plant species as the rubber canopy closed. *Pueraria phaseoloides* was the dominant species in the interrows during the first 1 to 2 years. As the canopy closed and shade increased (3 - 5 years old rubber), the amount of standing forage declined. The dominant plant species were mainly volunteer grasses (*Ottochloa nodosa*), planted legumes (*Calopogonium caeruleum* and *Pueraria phaseoloides*) and broadleaved weeds (*Mikania micrantha* and *Aystaysia intrusa*). The potential for animal production is therefore greatest during the immature period because of the higher forage dry matter availability at this time. It will be a challenge to introduce higher-yielding cultivated pastures into the rubber interrows which will be productive at lower light intensities. More studies are recommended to identify suitable forage species which have a high production potential and are able to sustain regular grazing in shaded environments.

The Botanal method used in this study was a useful technique. Using this method, we were able to record large numbers of samples in the field for yield and botanical composition as compared to the conventional system of cutting and weighing quadrats. The technique can be adopted for surveying forage resources under other plantation crops such as oil palm and coconut. Surveys of this nature are expensive in terms of labour requirement and time, and need to be well planned with objectives well defined. However, the baseline data obtained will be a useful guide for estimation of the animal production potential under different plantation crops and management systems.

Acknowledgments

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Productivity of Cover Crops and Natural Vegetation under Rubber in Malaysia

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Abstract

The productivity under regular cutting of leguminous cover crops and naturalised forages was measured under a wide range of light transmissions in a rubber plantation at the RRIM Research Station in Sg. Buloh in Central Malaysia. Annual dry matter production ranged from just under 7 t/ha/yr in young rubber (light transmission 60 – 100%) to less than 0.5 t/ha/yr in mature rubber (light transmission < 15%).

FORAGES under rubber plantations are a major source of feed for cattle, sheep and goat production in Malaysia and they consist of various grasses and broadleafed species which form a 'naturalised pasture'. If legume cover crops are sown at the time of rubber planting, these legumes usually dominate the naturalised species in the interrows of young rubber for the first 3-5 years of growth.

There is little information on the biomass production of forages under rubber. The level of production may be influenced by light transmission, age of rubber, type and fertility of soil, temperature, moisture and management practices. In rubber plantations, light is probably the most limiting factor controlling the productivity of forages. Chee and Faiz (these Proceedings) recently conducted a forage survey under rubber and reported that the standing forage biomass ranged from 2600 kg/ha in 1 – 2 years old rubber (light transmission of 92% of photosynthetically active radiation — PAR) to less than 600 kg/ha in 6 – 10 years old rubber (light transmission of 9% PAR). However, standing biomass is a measure of forage availability and not of forage productivity which is the determinant of the number of animals that can be supported.

To estimate the productivity of forages in the declining light regime under rubber, an experiment was designed which measured the yield of forages under a regular cutting regime in both immature and mature rubber.

Materials and Methods

The experiment was established in two clonal trial areas at the RRIM Experimental Station at Sg. Buloh in Central Malaysia. Sites in five-year-old rubber trees with light transmissions (LT) of 10%, 20%, 40% and 60% PAR, and in three-year-old rubber trees with light transmissions of 80% and 100% PAR were selected for the trial. There were 3 replicates of the 10%, 20%, 40% and 60% light regimes and 6 replicates of the 80% and 100% light regimes.

Plot size was 3 × 10 m across the rubber interrows and plots were fenced individually. The vegetation in the fenced area was initially cut at 15 cm above ground level and the cut material was discarded. The forages were then allowed to regrow for 2 – 3 months before the first harvest was carried out. Subsequent harvests were taken according to the rate of regrowth and varied from 2 – 3 months for the 80 and 100% PAR plots, 3 – 5 months for the 20 and 40% PAR plots, and 6 – 9 months for the 10 and 20% PAR plots. At each harvest, a 0.5 m wide band which extended across the interrow from one tree row to the next was cut at 15 cm above ground level. The cut material was separated into species and dried in an oven for dry weight determination. Light transmission was measured every two months using two integrating PAR meters. One was used to measure the incoming radiation over 10-minute periods outside the plantation in full sun, while the second was carried through the experimental area for simultaneous measurements in the plantation. Measurements were done on reasonably clear days between 1000 hours and 1400 hours.

Results and Discussion

At the time of the workshop the experiment had not been completed. Because of the different harvesting intervals in the various treatments, the availability of yield data varied from 6-12 months in the different treatments. All yield data have been converted by

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extrapolation to annual yields and have been plotted against the mean light transmission experienced in respective plots.

Overall, forage dry matter yield was strongly related to light transmission (Fig. 1). At high light transmissions of 60–100%, yields varied predominantly from 4.5 – 6.5 t/ha/yr. Within this high light transmission range, there appeared to be no relationship between light transmission and yield. However, dry matter yield was greatly reduced when light transmission fell below 50%. Chen and Othman (1983) and Wan Mohamed (1986) also reported standing biomass reductions from 5.5 – 9.5 t/ha under rubber and oil palm during the first two years of growth to below 1 t/ha when canopies closed.

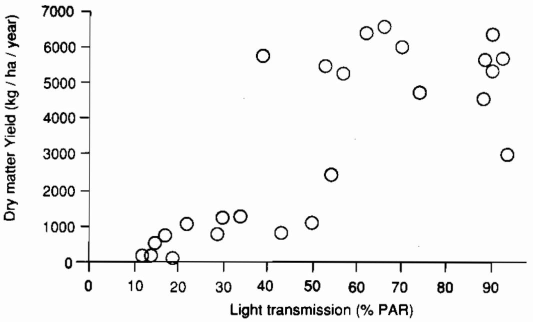

Fig. 1. Dry matter productivity of cover crops and naturally occurring forages under different light levels in rubber.

The forage composition in the various light transmission treatments varied (Table 1) even though the same leguminous cover crops were sown initially in both fields (experimental areas) and the management of these areas was identical. At high light transmission, the major forage species were *Calopogonium caeruleum*, *Paspalum conjugatum* and *Mikania micrantha*, while at low light transmissions the dominant species were *Asystasia intrusa* and *Paspalum conjugatum*. The rapid decline in yield between the light levels of 60 and 40% may have been related to a change in botanical composition. However, *Paspalum conjugatum* was present at both the high and low light levels.

Conclusions

Forage productivity under rubber was related to light transmission. The yield of forages was highest at light transmission levels of 60 – 100% but declined sharply once light transmission fell below 50%. Distinct changes in species composition were evident as light transmission declined.

Table 1. Forage composition under various light regimes of rubber.

Light transmission range (% PAR)	Species	Composition (%)
80–100	*Calopogonium caeruleum*	97
	Paspalum conjugatum	3
60–80	*Calopogonium caeruleum*	56
	Paspalum conjugatum	31
	Mikania micrantha	13
40–60	*Asystasia intrusa*	70
	Paspalum conjugatum	19
	Pueraria phaseoloides	6
	Mikania micrantha	2
30–40	*Asystasia intrusa*	89
	Paspalum conjugatum	12
10–20	*Asystasia intrusa*	55
	Paspalum conjugatum	38
	Mikania micrantha	8

Acknowledgments

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Last but not least, we are indebted to ACIAR for financial and institutional support. Our sincere appreciation is extended to Dr Graeme Blair, Dr Max Shelton, Dr Werner Stür, Dr Barry Norton and Dr John Wilson for their valuable contributions and assistance throughout the implementation of the experiments.

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Utilisation of Forage Resources from Vanilla-growing Areas under Coconuts in Bali

I.K. Mendra*, I.K. Rika*, M.G. Oka Nurjaya* and M. Gusti Oka*

Abstract

Over 5000 ha of vanilla are grown under coconuts in Bali. As a climber, vanilla requires a support structure and a shady habitat; tree legumes are used for this purpose. A large amount of forage is therefore generated by the vanilla system both from the occasional lopping of the tree legumes and the harvest of pasture growing between the rows of vanilla. A survey was undertaken to investigate the utilisation of this forage.

While 60% of farmers with ruminants used part of the loppings from the tree legumes as feed for their animals, the remaining 40% of farmers with ruminants used loppings exclusively for mulch and green manure. Most farmers with ruminants used the feed from the pasture at least partly for animal feeding. The cutting management imposed on tree legumes and pasture appeared to be directed towards the requirements of vanilla and not of the ruminants.

VANILLA was introduced to Bali in 1975. Since then the area of vanilla has steadily increased to over 5000 ha. As a climber, vanilla needs a support structure to climb over and it also requires a shady habitat in which to grow. In Bali, vanilla is therefore grown under coconuts and tree legumes are grown in rows under the coconuts to provide support and additional shade for the vanilla. The tree legumes are occasionally lopped to achieve the required light level. The largest areas of vanilla are found in Kabupatan (regency) Tabanan (2450 ha) and in Kabupatan Jembrana (1200 ha).

Since tree legumes are known to provide a large amount of high quality forage, it was assumed that cattle or goats would be associated with vanilla production. This assumption was tested by comparing the number of cattle and goat numbers in regions with large areas of vanilla with the number in adjacent regions without vanilla. However, no correlation was found and it was decided to conduct a survey of vanilla-growing farmers to investigate the fate of the large amount of forage generated by the vanilla/tree legume/coconut system.

Materials and Methods

The survey was conducted in Kabupatan Tabanan and Jembrana, since large areas of vanilla are grown in those regencies. The Kecamatan (districts) with the largest area of vanilla were selected for the survey. Four Kecamatan were selected in Tabanan and one in Jembrana. These were Pupuan (756 ha), Selemadeg (646 ha), Baturiti (423 ha) and Penebel (361 ha) in Tabanan, and Mendoyo (709 ha) in Jembrana. As for the selection of the Kecamatan, the Desa (village) with the largest vanilla area was selected within each Kecamatan. Once the Desas were selected, the rest of the selection process was based on random selection. Within each Desa, four Dusun (hamlets) were selected at random and in each of the selected Dusun 10 farmers were selected at random from vanilla-growing farmers. In total, 197 farmers agreed to participate in the survey. Of these, approximately 50% kept either cattle (mainly in Tabanan) or goats (mainly Jembrana).

Each farmer was visited by one of the authors and a questionnaire was completed. The surveyor also looked at the vanilla area of each farmer to visually estimate botanical composition of the pasture growing between the vanilla rows, and to cross-check some of the answers given in the questionnaire.

Results and Discussion

Support structure (tree legumes)

Originally, *Leucaena leucocephala* (leucaena) was used as the support tree legume for vanilla. However, psyllids have severely damaged leucaena in the last few years and almost all farmers have replaced or are

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in the process of replacing leucaena with other tree legumes. Table 1 shows that only 8% of respondents had not yet started to replace leucaena. The most frequently used replacement species was *Erythrina indica* (erythrina), but other species such as *Gliricidia sepium* (gliricidia) were also used (Table 1).

Table 1. Tree legumes used as support structure for vanilla (% of respondents).

Species	Respondents (%)
Gliricidia (exclusively)	1
Leucaena (exclusively)	8
Erythrina (exclusively)	19
Leucaena + gliricidia	2
Leucaena + erythrina	42
Gliricidia + erythrina	7
Leucaena + gliricidia + erythrina	19
Mixture including other species[a]	2
Total	100

[a] other species = calliandra and delundung

Pasture species grown under vanilla

No improved pasture species were encountered under vanilla. However, some farmers planted the grasses *Setaria sphacelata* and *Pennisetum purpureum* along the fence lines. Native pasture under vanilla consisted largely of a mixture of grasses which often included *Paspalum conjugatum* (Table 2). Other grasses, such as *Axonopus compressus* and *Imperata cylindrica* were also present in some areas. No legume species were found in any of the areas. *Imperata cylindrica* was mainly found at Mendoyo, which is a drier area than the other sites. This result is in accordance with the findings from a forage survey by Nitis et al. (1980) who concluded that *Paspalum* spp. are the dominant grass species in Bali.

Table 2. Pasture species grown between the rows of vanilla.

Species	Respondents (%)
Axonopus compressus	4
A. compressus + weed	7
Imperata cylindrica + *Paspalum conjugatum*	2
I. cylindrica + *P. conjugatum* + weed	10
P. conjugatum	5
P. conjugatum + *A. compressus*	2
P. conjugatum + weed	38
P. conjugatum + *A. compressus* + weed	31
Total	99

Cutting management of forages

Farmers with and without ruminants imposed a similar cutting management on tree legumes and pasture (Table 3). Tree legumes were cut mainly during the wet season and whenever there was excessive shading of vanilla. Trees were usually lopped 1–3 times per year and trees were lopped severely at each cut. Pastures were cut whenever there was excessive growth which occurred 4–6 times per year. As with trees, the pasture was cut back severely at each cut. It was concluded that the cutting management of both tree legumes and pasture was dependent on the best management for vanilla, not for the needs of ruminants.

Utilisation of forages

There were distinct differences in the utilisation of forages between farmers with and without ruminants (Table 4). While many more farmers with ruminants used part of the forage for feed than those without ruminants, 40% of farmers with ruminants did not use the forage generated by the tree legumes for animal feeding. This illustrated that lopping of the tree legumes in the vanilla system is directed towards vanilla rather than ruminant management. Pastures are mostly used for feed by farmers with ruminants, while those without ruminants use it largely for mulch. A large proportion of farmers indicated during the interviews that much of the forage, both from tree legumes and pasture, was used as mulch.

Conclusions

The most frequently used tree legume to replace leucaena as a support structure for vanilla was erythrina. The pasture grown between the vanilla rows consisted exclusively of native species and many of the pastures contained *Paspalum conjugatum*. The cutting management of tree legumes and pasture appeared to be determined by the requirements of vanilla rather than the ruminants. In fact, 40% of farmers with ruminants did not use the loppings from tree legumes as feed for their animals. Much of the forage generated by the vanilla system was used for mulch.

Acknowledgments

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Table 3. Management imposed on forages under coconut–vanilla system (% of respondents).

	Respondents with ruminants		Respondents without ruminants	
	Tree legumes	Pastures	Tree legumes	Pastures
Time of cutting				
When excessive	27	88	28	80
Wet season	54	6	55	14
Dry season	1	1	1	2
Before flowering	13	0	14	1
Others .	4	5	3	3
Total	100	100	100	100
Frequency of cutting				26
Occasionally (1–3/year)	69	20	76	68
Moderate (4–6/year)	22	71	22	2
Frequently (7–12/year)	3	4	1	3
Others (uncertain)	6	5	1	
Total	100	100	100	100
Intensity of cutting				
10–50%	16	4	22	7
51–100%	84	56	73	79
Others	0	48	5	14
Total	100	100	100	100

Table 4. Utilisation of forages generated in the coconut–vanilla system (% of respondents).

Utilisation	Tree Legumes		Pastures	
	Respondents with ruminants	Respondents without ruminants	Respondents with ruminants	Respondents without ruminants
Mulch (exclusively)	15	50	13	84
Feed (exclusively)	3	1	21	2
Green manure (exclusively)	2	4	4	1
Discard and fire wood (exclusively)	2	0	0	0
Combinations including feed	57	5	62	13
Combinations excluding feed	21	41	0	0
Total	100	101	100	100

Reference

Nitis, I.M., Lana, K., Sudana, I.B., Sutji, N.N. and Sarka, I.G.N. 1980. Survey data makanan ternak: persediaan dan kebutuhan hijauan makanan ternak di Bali. Laporan FKHP, UNUD: Denpasar, 218 p.

New Forage Species for Coconut Plantations in Bali

I.K. Rika*, I.K. Mendra*, M. Gusti Oka* and M.G. Oka Nurjaya*

Abstract

An experiment was conducted at Pulukan in Bali during 1988 and 1989 to evaluate the performance, in terms of dry matter yield and persistence under regular cutting, of 37 grass and 35 herbaceous legume species. Most species were selected from the CSIRO forage germplasm collection held in Brisbane, Australia for their assumed shade tolerance.

Species which showed both good regrowth and persistence, although lower total yields over 11 harvests than some less persistent species, were the legumes *Arachis* sp. CPI 29986 and *Arachis* sp. CPI 12121, and the grasses *Paspalum notatum* CPI 11864, *P. notatum* cv. Competidor and *Axonopus compressus* local variety.

THE successful introduction of forages under plantation crops requires high quality species that are well adapted not only to the soils and climate of the region but also to the special requirements of plantation crop systems. These special characteristics are (a) adaptation to reduced light regimes, (b) low growth habit (except for cut and carry situations) as tall species may interfere with normal plantation management, and (c) minimal competitiveness with the plantation crop. Leguminous species may meet this latter characteristic more readily than grass species.

There is a number of naturally occurring species which may be found in plantation crops in the tropics which meet some of these characteristics, namely *Axonopus compressus, Paspalum conjugatum* and *Centrosema pubescens*. However, they generally lack sufficient vigour to maintain weed-free swards under regular grazing regimes. There is a number of improved species which improve the productivity and quality of forages in plantation crops (Shelton et al. 1987). Nevertheless, new species are required which more specifically meet the range of plantation environments that occur in southeast Asia and the Pacific.

Accordingly, a series of coordinated species evaluation experiments was conducted in coconut plantations at Bali and North Sulawesi in Indonesia and at the Rubber Research Institute of Malaysia at Sungei Buloh. In Indonesia, species are required for 'cut and carry' and for intensively grazed sites. Species which improve the quality of pasture and extend the growing season will be particularly valuable. In Malaysia, species are needed which are adapted to the declining light environment of maturing rubber and which are suitable for grazing by sheep. The overall objective was to identify new forage genotypes which were superior in their persistence of yield compared to existing species. This paper describes the materials and methods, which were common to all experiments, and the results of the Bali experiment. The results of the North Sulawesi and Sungei Buloh experiments are given in separate papers.

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Materials and Methods

Location

The trial was conducted under a stand of old coconuts, with new palms interplanted, at Pulukan village about 60 km west of Denpasar, Bali. Average annual rainfall at the site is 2070 mm with most rain falling between October and April. There is a distinct dry season from June to August in most years. Rainfall during the experimental period followed the long-term trend. The soil is a fertile sandy clay loam with a pH of 6 to 7. The light transmission at 10 a.m. on a sunny day was 58% PAR.

Treatments and design

There were 37 species of grasses and 35 species of herbaceous legumes in Bali (Table 1). Grasses and legumes were chosen on the basis of their assumed shade tolerance and were obtained from Mr Ron Williams of the Tropical Forage Genetic Resources Centre, CSIRO, Brisbane, Australia.

An unreplicated augmented design was used with a single plot of all species, and the systematic replication of two check grass species *Panicum maximum* cv. Riversdale and *Brachiaria decumbens* cv. Basilisk and two check legume species *Centrosema pubescens* and *Pueraria phaseoloides* to give five replications of each check species. Nursery plots, comprising two single rows of each species, were planted next to the main plots. These plants were grown without cutting to observe flowering behaviour, seed production, and disease and insect incidence.

Plot size was 1 × 1 m for main plots and 0.5 × 1 m for nursery plots. Seedlings, previously germinated in a shadehouse, were planted on 20 cm squares to give 25 plants per main plot and 10 plants per nursery plot. Plots were transplanted into the field in June 1988.

Measurements

Yield of each species was obtained by cutting the central area of each main plot (0.36 m^2 containing nine plants). Fresh samples were separated into leaf, stem and weeds and then air-dried before oven-drying in an oven at 70°C to determine total dry weight. The first harvest was taken three months after planting (18 September) and then plots were cut regularly every two months until 18 May 1990. There were 11 harvests.

The height of cutting varied from 5 to 20 cm, depending on the morphology of the species. Tall species were cut at 20 cm, prostrate species at 5 cm, while species of intermediate height were cut at 10 cm. The growth performance of the species including vigour, plant survival, pest incidence, flowering behaviour and seed production was assessed at each harvest using a rating system.

Results and Discussion

Legumes

The results of the yield measurements for legumes are shown in Table 1a. There was a general trend of reducing yield over the 11 harvests although this varied among species. The two highest-yielding species at harvest 1, *Desmodium intortum* CPI 46552 and *D. intortum* cv. Greenleaf, gave initial yields of 360 and 630 g/m^2 respectively, and remained the highest-yielding species until the final harvest although their yields and vigour were greatly reduced to 83 and 75 g/m^2 respectively. Another group of twining legumes was initially lower-yielding but gave moderate final yields (60-65 g/m^2) indicating good persistence under the 2-monthly cutting regime. These included *Pueraria phaseoloides* and *Centrosema pubescens* CPI 58575.

A further group of prostrate legumes was initially low-yielding but increased in yield over the period of the experiment. *Arachis* sp. CPI 29986 and *Arachis* sp. CPI 12121 were two species in this category.

Leaf percentage was generally higher than 50% for most species but was particularly high for the *Arachis* species. Insect and disease incidence was greater in legumes than in grasses and affected growth of some species seriously (e.g. *Neonotonia wightii*). Weed invasion was high in *Arachis* species plots.

Grasses

The grasses were higher-yielding than the legumes although there was a similar trend of decreasing yield with time (Table 1b). The species which were initially highest-yielding showed the greatest decline in vigour indicating poor persistence under the 2-monthly cutting regime and decline in soil fertility with time. These were the tall-growing species including the *Panicum maximum* species, the *Digitaria milanjiana* species, *Paspalum dilatatum*, *Paspalum malacophyllum* and *Setaria sphacelata* cv. Splenda which produced yields in the range from 550 to 780 g/m^2.

The best prostrate species behaved differently. Their yields were initially low (60-110 g/m^2) but they maintained or increased yields over the 11 harvests indicating excellent persistence under regular defoliation. The principal species were *Paspalum notatum* CPI11864 and cv. Competidor, *Axonopus affinis* and *A. compressus* (local variety). The *Paspalum notatum* species were notable for their high leaf percentage and low weed content (Table 1b). Grass species were not greatly affected by insects and diseases.

Other species which were lower-yielding but formed dense relatively weed-free swards were *Brachiaria humidicola*, *Paspalum dilatatum*, *P. wettsteinii*, *Digitaria milanjiana* CPI59775 and *Stenotaphrum secundatum*.

Conclusions

The data obtained to date indicate that there is a number of species that should be further tested in farming systems. The tall-growing grasses may be suitable for cut-and-carry systems especially if cutting management is lenient. The use of fertilizers may extend the effective life of these species although this aspect was not tested. A number of twining legumes may be useful cover crops in new plantations for weed control and forage production.

However, for regularly grazed situations the prostrate grasses and legumes may have superior persistence and should be further tested in grass-legume combinations and on farms.

Table 1a. Dry matter yield, mean leaf percentage and maximum weed percentage of species evaluated under coconuts in Bali (each value = mean of one or more harvests).

Species	Dry matter yield Harvest 1 wet	2-4 wet ($g/m^2/2$ months)	5-7 dry	8-11 wet	Mean leaf (%)	Max. weed (%)
a) Legumes						
Desmodium intortum Grp.J CPI 46552	361	219	100	83	46	2
Desmodium intortum cv. Greenleaf	633	214	103	75	40	14
Pueraria phaseoloides (commercial)	122	114	58	64	59	34
Arachis sp. CPI 29986 (vegetative)	67	114	33	61	64	37
Centrosema pubescens CPI 58575	136	108	33	61	63	58
Neonotonia wightii cv. Malawi	81	133	42	58	49	72
Arachis sp. CPI 19898 (vegetative)	108	92	39	58	70	11
Arachis sp. CPI 12121 (vegetative)	19	78	39	56	65	33
Neonotonia wightii cv. Tinaroo	169	131	94	47	54	8
Teramnus labialis cv. Semilla Clara	153	131	67	42	56	26
Arachis pintoi CPI 58113	117	69	33	42	69	81
Psophocarpus palustris (local) Bali	106	81	22	42	50	58
Arachis repens CPI 28273 (vegetative)	92	94	42	36	67	73
Desmodium ovalifolium Q 8194	86	117	33	33	61	40
Desmodium intortum Grp.C CPI 43201	136	86	44	31	58	52
Desmodium aparine CPI 33814	100	83	44	31	49	74
Vigna hosei CQ 729	56	67	28	31	63	78
Centrosema pubescens (common)	133	94	22	31	59	67
Vigna lasiocarpa Grp.A CPI 34436	50	58	17	28	47	67
Centrosema pubescens cv. Belalto	167	108	44	25	57	81
Desmodium sp. Grp. A CPI 49668	144	142	28	25	56	81
Vigna luteola cv. Dalrymple	97	78	31	22	55	71
Macrotyloma axillare cv. Archer	78	75	39	19	51	68
Desmodium scorpiurus CPI 87514	86	47	19	19	53	93
Desmodium heterophyllum cv. Johnstone	64	128	25	17	54	81
Aeschynomene americana cv. Glenn	139	172	14	11	45	0
Centrosema sagittatum CPI 82277	103	56	11	8	57	0
Cassia rotundifolia cv. Wynn	50	83	8	8	50	0
Centrosema macrocarpum CPI 95531	217	92	28	3	51	81
Desmodium heterocarpon cv. Florida	69	133	6	0	48	0
Calopogonium mucunoides (commercial)	164	97	6	0	53	0
Lotus pedunculatus cv. Maku	58	25	6	0	40	0
Vigna parkeri cv. Shaw	25	8	6	0	48	0
Trifolium semipilosum cv. Safari	19	8	6	0	43	0
Cassia pilosa CPI 57503	108	153	3	0	36	0
Desmodium adsendens Grp.A CPI 93125	25	14	3	0	62	0
Vigna oblongifolia.aff CPI 60433	0	0	0	0	75	0
Harvest means	119	97	33	33	55	54

Table 1b. Dry matter yield, mean leaf percentage and maximum weed percentage of species evaluated under coconuts in Bali (each value = mean of one or more harvests).

Species	Dry matter yield (g/m²/2 months) Harvest 1 wet	2-4 wet	5-7 dry	8-11 wet	Mean leaf (%)	Max. weed (%)
b) Grasses						
Panicum maximum cv. Riversdale	872	261	108	186	54	0
Paspalum malacophyllum CPI 27690	731	222	175	156	47	0
Paspalum dilatatum (commercial)	567	253	122	156	63	9
Paspalum notatum CPI 11864	61	122	92	156	89	0
Panicum maximum cv. Gatton	708	381	161	147	35	0
Paspalum plicatulum cv. Bryan	427	281	117	147	60	0
Brachiaria decumbens cv. Basilisk	325	244	139	139	43	5
Digitaria milanjiana CPI 41192	703	178	156	136	60	0
Digitaria milanjiana CPI 59775	317	208	106	128	40	0
Panicum maximum cv. Petrie	697	208	169	125	40	0
Axonopus affinis (commercial)	100	119	78	117	73	28
Paspalum sp. (local) Bali	194	158	89	111	50	21
Digitaria smutsii cv. Premier	253	164	103	108	83	4
Brachiaria brizantha CPI 15890	494	225	83	108	45	14
Bothriochloa pertusa	314	192	111	106	50	46
Paspalum notatum cv. Competidor	81	106	100	106	80	0
Digitaria milanjiana CPI 59721	586	247	94	106	49	0
Setaria sphacelata cv. Splenda	672	161	89	106	39	7
Paspalum wettsteinii (commercial)	281	153	89	94	61	0
Axonopus compressus (local) Bali	111	92	69	94	74	7
Panicum maximum cv. Rumuruti	633	170	56	94	41	0
Brachiaria humidicola cv. Tully	200	189	103	83	51	0
Digitaria sp. (local) Bali	297	150	53	69	43	73
Paspalum simplex CPI 27709	256	258	89	67	46	70
Panicum maximum cv. Embu	297	175	67	67	37	40
Bothriochloa insculpta CPI 59584	256	153	75	61	46	17
Paspalum commersonii CPI 15705	363	203	53	61	41	0
Panicum laxum CPI 113582	106	111	53	61	61	11
Paspalum conjugatum CPI 60059	242	153	64	50	43	0
Panicum laxum CPI 53932	106	94	64	47	61	36
Digitaria pentzii CPI 41190	147	83	53	44	78	37
Avena sp. (local) Bali	256	89	69	42	40	60
Paspalum scrobiculatum cv. Paltridge	378	125	42	39	47	77
Acroceras macrum CPI 62122	150	94	58	22	45	53
Stenotaphrum secundatum (ex) Brisbane	16	19	22	23	73	89
Harvest means	397	189	97	108	51	15

Acknowledgments

This work was carried out as part of an ACIAR-funded collaborative research program entitled 'Improvement of Forage Productivity in Plantation Crops', between Udayana University, Bali, Indonesia and The University of Queensland, Australia.

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Forage Species for Coconut Plantations in North Sulawesi

D.A. Kaligis* and C. Sumolang,*

Abstract

An experiment was conducted at Kayuwatu near Manado in North Sulawesi during 1988 and 1989 to evaluate the performance, in terms of dry matter yield and persistence under regular cutting, of 37 grass and 40 legume species. Most species were selected for their likely shade tolerance from the Australian Tropical Forages Genetic Resource Centre, CSIRO, Brisbane, Australia.

Species which showed good regrowth and persistence, but slightly lower total yields over 10 harvests, were the legumes *Arachis pintoi*, *A. repens*, *Arachis* sp. CPI 29986, *Desmodium ovalifolium* and *D. heterophyllum*; and the grasses *Paspalum notatum* cv. Competidor, *P. notatum* CPI 11864, *P. wettsteinii*, *Axonopus compressus* (local), and *Digitaria milanjiana* CPI 59721.

IN North Sulawesi farmers raise cattle in conjunction with other farming activities and regard livestock as draft animals and as savings. As in Bali, feed resources consist of local grasses which are generally of low quality. Most local species such as *Paspalum conjugatum*, *Centrosema pubescens* and *Calopogonium mucunoides* are not resistant to heavy grazing. An exception is *Axonopus compressus* which is often found in heavily grazed areas. However, almost all grazing areas are dominated by broadleaf weeds and shrubs. This shows that the growth of the naturally occurring palatable grasses and legumes is not sufficiently vigorous to suppress weeds. Grazing management is generally poor and overgrazing frequently occurs.

This species evaluation program attempted to identify forages which are adapted to the environmental conditions of North Sulawesi, grow well under the shaded conditions in coconut plantations, and are persistent under heavy grazing and low management inputs.

Materials and Methods

The experiment was conducted at Kayuwatu (close to sea level) near Manado Airport and which receives an average rainfall of 2700 mm. Rainfall distribution is fairly even, except for a period of lower rainfall (100–150 mm per month) from July to September. Once in approximately every five years a more severe dry season occurs. During the experiment, rainfall was slightly higher than the long-term average, particularly during the drier period (Fig. 1). The pH of the fertile, sandy loam soil is around 6. Light transmission (PAR) at the site under mature tall coconuts averaged 73% at 10.00 a.m. on a sunny day.

There were 37 grass and 40 legume species (Table 1). These consisted of the same introduced species as in Bali plus some promising local species. The design and management of the experiment was identical to those in Bali and seedlings were transplanted into the field in June 1988.

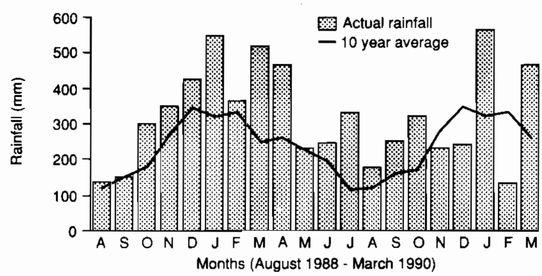

Fig. 1. Long-term and actual rainfall during the experimental period at Kayuwatu, Manado, Indonesia.

Results and Discussion

Dry matter yields and mean leaf percentage of the legumes and grasses are presented in Table 1.

Legumes

Species could be grouped according to their growth habit. Species with an upright growth habit such as *D. intortum* Grp.J. CPI 46552, *D. intortum* cv. Greenleaf and *Desmodium* sp. Grp. A. CPI 49668, gave the

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Table 1. Dry matter yield and mean leaf percentage of species evaluated under coconuts at Manado (each value = mean of three or four consecutive harvests).

Species	Dry matter yield Harvest 1–3	4–6 (g/m²/2 months)	7–10	Mean % leaf
Legumes				
Desmodium intortum Grp.J CPI 46552	222	172	131	60
Desmodium aparine CPI 33814	139	142	117	55
Centrosema pubescens CPI 58575	86	128	103	68
Teramnus labialis cv. Semilla Clara	103	86	103	64
Centrosema pubescens cv. Belalto	61	111	100	63
Desmodium intortum cv. Greenleaf	319	128	94	57
Arachis repens CPI 28273 (vegetative)	42	78	94	84
Desmodium ovalifolium Q 8194	89	92	78	76
Centrosema pubescens (common)	75	83	78	69
Cassia rotundifolia cv. Wynn	6	44	78	52
Desmodium adsendens Grp.A CPI 93125	61	83	75	66
Arachis pintoi CPI 58113	81	83	72	81
Desmodium heterophyllum cv. Johnstone	81	81	69	65
Mimosa sp. (local) Manado	114	108	61	52
Desmodium sp. Grp. A CPI 49668	217	92	61	60
Pueraria phaseoloides (commercial)	81	81	58	78
Vigna hosei CQ 729	47	56	47	80
Arachis sp. CPI 19898 (vegetative)	28	42	47	72
Calopogonium mucunoides (commercial)	64	19	44	68
Arachis sp. CPI 29986 (vegetative)	47	47	42	68
Centrosema pubescens (local) Manado	31	39	39	77
Desmodium intortum Grp.C CPI 43201	44	28	39	75
Desmodium scorpiurus CPI 87514	78	78	36	65
Neonotonia wightii cv. Tinaroo	106	72	22	62
Neonotonia wightii cv. Malawi	28	33	19	62
Aeschynomene americana cv. Glenn	336	33	17	38
Cassia pilosa CPI 57503	78	33	14	60
Vigna luteola cv. Dalrymple	42	17	6	65
Centrosema macrocarpum CPI 95531	192	33	0	56
Desmodium heterocarpon cv. Florida	28	14	0	47
Vigna lasiocarpa Grp.A CPI 34436	19	6	0	69
Calopogonium mucunoides (local) Manado	36	0	0	64
Centrosema sagittatum CPI 82277	14	0	0	63
Macrotyloma axillare cv. Archer Grp.A	14	0	0	48
Desmodium triflorum (local) Manado	6	0	0	80
Lotus pedunculatus cv. Maku	3	0	0	–
Vigna parkeri cv. Shaw	0	0	0	–
Vigna oblongifolia.aff CPI 60433	0	0	0	–
Arachis sp. CPI 12121 (vegetative)	0	0	0	–
Trifolium semipilosum cv. Safari	0	0	0	–
Mean harvest dry matter yield	75	58	53	

highest dry matter production in the early harvests 1–3, but their yield decreased sharply in later harvests. It was suspected that species with a sharply declining yield were either not resistant to regular defoliation or required a higher fertility. No fertilizer was applied to the experiment and some nutrients may have been limiting after several harvests. Other species of medium height such as *C. pubescens* CPI 58575, *C. pubescens* (common) and *Teramnus labialis* cv. Semilla Clara had a more even dry matter production throughout the experiment. Lastly, low growing species such as *Arachis repens*, *A. pintoi*, *D. ovalifolium* and *D. heterophyllum* cv. Johnstone gave low initial yields but higher yields in later harvests. The overall yield of this group was lower than that of the higher-growing species, but they showed fast regrowth, better ground

Table 1 *(Cont'd)*

Species	Dry matter yield Harvest 1-3	4-6 (g/m²/2 months)	7-10	Mean % leaf
Grasses				
Brachiaria decumbens cv. Basilisk	564	311	278	47
Brachiaria decumbens (local) Manado	328	292	278	50
Panicum maximum cv. Riversdale	1294	281	275	54
Digitaria milanjiana CPI 59721	356	264	269	51
Setaria sphacelata cv. Splenda	744	167	222	42
Brachiaria humidicola cv. Tully	469	275	197	55
Paspalum plicatulum cv. Bryan CPI 21379	644	256	197	68
Paspalum notatum cv. Competidor	286	192	194	99
Digitaria milanjiana CPI 41192	194	189	189	63
Panicum maximum cv. Embu	478	192	186	37
Paspalum notatum CPI 11864	317	156	169	99
Paspalum scrobiculatum cv. Paltridge	356	161	139	47
Paspalum conjugatum CPI 60059	225	158	136	42
Paspalum dilatatum (commercial)	464	256	128	65
Axonopus compressus (local) Manado	194	150	125	87
Digitaria milanjiana CPI 59775	194	153	122	47
Bothriochloa insculpta CPI 59584	356	197	119	39
Paspalum wettsteinii (commercial)	258	219	114	63
Panicum maximum cv. Petrie	386	203	103	41
Digitaria pentzii CPI 41190	67	169	97	82
Paspalum malacophyllum CPI 27690	356	186	86	55
Panicum maximum cv. Rumuruti	375	214	83	47
Bothriochloa pertusa	172	158	83	53
Panicum maximum cv. Gatton	464	181	75	51
Paspalum commersonii CPI 15705	336	122	69	51
Paspalum conjugatum (local) Manado	267	83	67	58
Digitaria smutsii cv. Premier CPI 38869	94	94	64	81
Acroceras macrum CPI 62122	108	50	50	45
Paspalum simplex CPI 27709	108	89	47	50
Panicum laxum CPI 113582	117	89	44	65
Brachiaria mutica (local) Manado	236	78	25	36
Local grass (local) Manado	39	19	17	51
Panicum laxum CPI 53932	39	14	0	42
Stenotaphrum secundatum (local) Brisbane	0	0	0	–
Panicum laxum CPI 113580	0	0	0	–
Axonopus affinis (commercial)	0	0	0	–
Mean harvest dry matter yield	408	178	147	

cover and higher persistence, and they dominated the weeds surrounding the plots. All of these species possessed a high proportion of leaf.

It was suspected that the medium and low-growing species were more resistant to regular defoliation than the more upright species. Persistence under heavy grazing is probably the most important factor determining the success of species in North Sulawesi pastures.

The low initial yield of *Cassia rotundifolia* was caused by a fungal disease which killed some plants. It recovered, however, and yielded well in later harvest.

Grasses

The yield of grasses was generally higher than that of legumes (Table 1). Nearly all species showed a decline in yield regardless of their growth habit. It was suspected that nitrogen may have limited the yield of grasses. As for legumes, productivity of grasses was associated with growth habit. Dry matter production of many of the erect grasses was high initially but dropped sharply after the first few harvests. Some of the species which fell into this group were *Panicum maximum* cv. Riversdale, *Setaria sphacelata* cv. Splenda and *Paspalum plicatulum*. However, there were some species which increased or decreased yield only slightly between harvests 4–6 and 7–10. Examples were *Brachiaria decumbens* (local), *Digitaria milanjiana* CPI 59721, *P. maximum* cv. Riversdale, *Setaria sphacelata* cv. Splenda and *P. notatum* CPI 11864. Although the dry matter productions of *P. notatum* cv. Competidor and *P. notatum* CPI 11864 were not the highest, it is likely that these grasses, because of their low sward-forming growth habit, will persist and provide stable pastures. They also had a high proportion of leaf. *Panicum maximum* cv. Riversdale, with its high yield potential, may be suited for a fertilised cut-and-carry situation.

Conclusions

The evaluation showed clearly that there are a number of legumes and grasses which appear promising. However, there are still questions which need to be answered regarding their ability to grow in mixtures and to suppress weed growth, before they can be recommended for pastures under coconut plantations.

The objective of this experiment was to identify species suited for use by small farmers who tether cattle and for larger coconut plantation enterprises which practice herd grazing. Accordingly, legumes and grasses are required which are persistent under heavy grazing and under poor management. Some of the species which may possess the necessary characteristics are presented in Table 2.

Although these species gave lower yields than other species, they showed generally good seedling vigour and resistance to diseases and insects. Further, most showed a very good ground cover and indicated an ability to compete with weeds. Because of these characteristics, it is predicted that these species will be adapted to the grazing systems practised in North Sulawesi.

Acknowledgments

This work was carried out as part of an ACIAR-funded collaborative research project, entitled 'Improvement of Forage Productivity in Plantation Crops', between Sam Ratulangi University at Manado, Indonesia and The University of Queensland, Australia.

Table 2. Species considered persistent to heavy grazing.

Species	Disease/ insect attack	Ground cover %	Seedling/ plant replacement	Growth habit
a. Legumes				
A. repens CPI 28273	none	100	high	low
A. pintoi CPI 58113	none	100	high	low
D. ovalifolium Q 8194	none	100	high	low
Arachis sp. CPI 29986	none	80	high	low
D. heterophyllum cv. Johnstone	none	100	high	low
b. Grasses				
P. notatum cv. Competidor	none	100	high	low
P. notatum CPI 11864	none	100	high	low
A. compressus (local)	none	100	high	low
P. wettsteinii	none	80	high	low
P. milanjiana CPI 59721	none	80	high	low

Forage Species for Rubber Plantations in Malaysia

K. F. Ng*

Abstract

Two experiments were conducted at the Rubber Research Institute of Malaysia Research Station at Sungei Buloh in 1988–89 to evaluate the performance, in terms of dry matter yield and persistence under regular cutting, of 41 grass and 46 legume species in experiment 1, and 10 grass and 14 legume species in experiment 2. Most species were selected for their assumed shade tolerance from the CSIRO forage germplasm collection held in Brisbane, Australia.

Species which showed good regrowth and persistence under the declining light environments of maturing rubber over six harvests were the grasses *Panicum maximum* cv. Riversdale, *Panicum maximum* cv. Vencedor, *Brachiaria brizantha*, *B. humidicola*, *B. dictyoneura* and *Paspalum notatum* CPI 11864; and the legumes *Stylosanthes scabra* cv. Seca and *S. guianensis* CIAT 184. Other species which were lower-yielding but which showed promise were the grasses *Paspalum wettsteinii* and *Stenotaphrum secundatum*, and some *Arachis* spp.

In rubber plantations and in organised smallholder land schemes such as FELDA, FELCRA, RISDA and other State-run schemes, it has been management policy to grow leguminous covers in the rubber interrows. It is also normal practice to plant a mixture of covers, such as *Calopogonium mucunoides, Pueraria phaseoloides* and *Calopogonium caeruleum* or *Centrosema pubescens*. These legume mixtures will persist under rubber up to the third or fourth year of rubber growth except for *Calopogonium caeruleum*, which may persist even after the rubber trees have attained maturity.

In the smallholder sector, the scenario is somewhat different. The smallholdings are either cultivated with short-term cash crops which help to generate some income during the first 1–2 years of rubber growth, or the interrows are left to natural weed species. With the cessation of intercropping, eventually both grass and broadleafed weed species will dominate. The major limitation to optimum livestock production, and particularly sheep in Malaysia, is therefore the shortage of high quality forage for animal feeding (Wong 1989).

Work on evaluation of introduced grass and legume species for forage production in the open began in 1972 (Wong et al. 1982). However, no evaluation of introduced species has ever been carried out under rubber.

For these reasons, an experiment was established to evaluate a number of introduced grass and legume species in terms of their yield, persistence and degree of shade tolerance for sheep grazing under rubber.

Materials and Methods

Two independent trials were set up, designated as experiment 1 and experiment 2 in field 14 of the Rubber Research Institute of Malaysia Experiment Station at Sg. Buloh. In experiment 1, a total of 41 grass, 46 legume and 2 broad-leafed species were evaluated under rubber with an initial PAR light transmission of 65% in the rubber interrows. In experiment 2, 10 grass, 14 legume and 1 broad-leafed species were evaluated under rubber with an initial PAR light transmission of 90%.

Experiment 1 was planted in January 1989. Basal application of NPK fertilizers was given to the whole experimental site plus magnesium limestone prior to planting at rates of 20 kg/ha N, 45 kg/ha P_2O_5, 25 kg/ha K_2O, and 500 kg/ha magnesium lime. Plot size was 1 × 1m with 25 plants/plot. Yield samples were taken from the central 9 plants (0.36 m^2). The experimental site was maintained weed-free. The first harvest commenced 73 days after planting. Subsequent harvests up to the third were carried out at 2-monthly intervals, thereafter, due to slow regrowth, at 3-monthly intervals.

In experiment 2, a smaller range of high-yielding species was selected from a preliminary small plot trial and planted in March 1989. The basal fertilizer application was as for experiment 1. The first harvest

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was in May 1989, 67 days after planting. Subsequent harvests were carried out at 2-monthly intervals.

Both the experiments were replicated twice. The total rainfall during the growing period is shown in Table 1. The soil texture and nutrient levels are shown in Table 2.

Table 1. Rainfall distribution at RRIM Experiment Station at Sg. Buloh, Selangor (1989-90).

Month	Year	
	1989 (mm)	1990 (mm)
January	174	60
February	241	172
March	241	122
April	170	213
May	117	211
June	88	
July	43	
August	150	
September	344	
October	276	
November	279	
December	260	
Total	2383	

Table 2. The physical and chemical properties of soil in experiments 1 and 2 at the RRIM Experiment Station, Sg. Buloh.

Parameter	Analysis
Soil series	Sg. Buloh
Coarse sand (%)	61
Fine sand (%)	27
Silt (%)	4
Clay (%)	8
pH	4.5
Organic C (%)	3.10
Total N (%)	0.25
P available (ppm)	30
K exch. (m.e. %)	0.10
Ca exch. (m.e. %)	0.09
Mg exch. (m.e. %)	0.06
Mn total (p.p.m)	14

Different cutting heights were adopted depending on the growth habit of the species. Tall species were cut at 20 cm, medium height species at 15 cm, and the low–growing species at 10 or 5 cm from the ground. Data on dry matter yield, coverage, susceptibility to pests and disease, and seeding behaviour were recorded.

Results and Discussion

Experiment 1

The dry matter yields of the best performing species are presented in Table 3. In Table 3, the overall mean yields of the 20 grass species indicated that there was a decreasing trend from harvests 1 to 6. This reduction in yield could possibly be attributed to two factors, viz., a drastic decline in light transmission from 53% at harvests 1 and 2 to 19% at harvests 5 and 6, and, secondly the cutting pressure of the 6 harvests spread over 16 months.

The ten high-yielding grass species, based on dry matter yield, were all *Panicum maximum* or *Brachiaria* spp. The highest yielding species, *Panicum maximum* cv. Riversdale recorded a yield of 20 t/ha/yr against 7 t/ha/yr for *Asystasia intrusa*, a three-fold improvement. Dry matter yields of *Asystasia intrusa* ranging from 3–10 t/ha/yr have been reported by Wong (1989).

If yield of species from harvests 5 and 6 is considered an indication of persistence under regular cutting and declining light, the five most persistent species were *Panicum maximum* cvv. Riversdale and Vencedor, *Brachiaria dictyoneura* MARDI, *Brachiaria humidicola* MARDI and *Paspalum notatum* CPI 11864.

The mean yield of legume species was generally much lower than those of the grasses. The high-yielding legume species were *Stylosanthes scabra* cv. Seca, *Stylosanthes guianensis* CIAT 184, *Stylosanthes hamata* cv. Verano, *Stylosanthes guianensis* cvv. Endeavour and Graham, and *Centrosema macrocarpum*, all of which recorded a yield exceeding 36 g/m^2/month. All species showed a dramatic decline at the last two harvests. It was reported that *Stylosanthes guianensis* cvv. Endeavour and Cook produced higher yield than the other legume species evaluated (Eng et al. 1978), although these two species died out 3–5 years after planting.

Experiment 2

A list of grass species evaluated in Experiment 2 is shown in Table 4. Due to higher light transmission in this trial (reduced from 90% at harvest 1 to 50% at harvest 6), the mean dry weight of species was greater than that of the same species in experiment 1. Similarly the reduction in yield from harvests 1 and 2 to harvests 5 and 6 was less.

The highest-yielding species over the six harvests were *Panicum maximum* cv. Vencedor, *Brachiaria brizantha* and *Panicum maximum* cv. Riversdale. The highest-yielding species at the final harvest were *Brachiaria humidicola, B. brizantha, B. dictyoneura* and *Panicum maximum* cv. Riversdale, indicating the persistence of these species.

The dry matter yield of the legume species in

Table 3. Dry matter yields of best-performing species in experiment 1.

Species	Dry matter yields ($g/m^2/month$) Harvests 1 and 2 (L.T. 53%)	Harvests 3 and 4 (L.T. 30%)	Harvests 5 and 6 (L.T. 19%)	Mean
Grasses				
Panicum maximum cv. Riversdale	272	156	72	167
Brachiaria decumbens cv. Basilisk	292	175	5	157
Brachiaria brizantha	231	158	22	137
Panicum maximum cv. Vencedor	194	144	55	131
Brachiaria dictyoneura	181	161	42	128
Panicum maximum cv. Gatton	161	150	39	117
Panicum maximum cv. Embu	172	114	11	99
Brachiaria decumbens MARDI	97	133	50	93
Brachiaria humidicola MARDI	83	133	58	93
Panicum maximum cv. Rumuruti	131	119	22	91
Digitaria setivalva	131	111	28	90
Asystasia intrusa	106	69	14	63
Paspalum notatum CPI 11864	31	56	44	44
Paspalum wettsteinii	42	50	22	38
Paspalum simplex	42	53	14	36
Paspalum notatum cv. Competidor	28	50	22	33
Paspalum conjugatum	44	36	14	31
Axonopus compressus	31	31	14	25
Cyrtococcum oxyphyllum	31	25	3	20
Stenotaphrum secundatum	18	19	5	14
Mean	116	97	28	80
Legumes				
Stylosanthes scabra cv. Seca	78	92	50	73
Stylosanthes guianensis CIAT 184	92	92	33	72
Stylosanthes hamata cv. Verano	75	89	16	60
Stylosanthes guianensis cv. Graham	111	44	16	57
Stylosanthes guianensis cv. Endeavour	78	53	19	50
Centrosema macrocarpum	67	42	0	36
Arachis sp. CPI 12121	33	36	14	28
Centrosema pubescens	42	17	8	22
Centrosema pubescens cv. Belalto	36	28	3	22
Arachis sp. CPI 29986	28	19	14	20
Pueraria phaseoloides	28	25	8	20
Arachis pintoi cv. Amarillo	44	11	1	20
Calopogonium caeruleum	25	25	3	18
Calopogonium mucunoides	31	0	0	10
Mean	55	41	13	36

* L.T. = light transmission

experiment 2 showed a similar trend to that observed for the grasses with higher initial yields and smaller declines in yield with each subsequent harvest (Table 4). In general, most *Stylosanthes* species performed well with *Stylosanthes scabra* cv. Seca, *Stylosanthes guianensis* CIAT 184, *Stylosanthes guianensis* cvv. Cook and Endeavour outstanding. The highest yielder, *Stylosanthes scabra* cv. Seca, gave 1.5 times more than the local *Asystasia intrusa* and 3.0 times more than the local *Pueraria phaseoloides*. Persistence of yield was best in *Stylosanthes guianensis* CIAT 184.

Table 4. Dry matter yields of best performing species in experiment 2.

Species	Dry matter yields (g/m2/month) Harvests 1 and 2 (L.T. 78%)	Harvests 3 and 4 (L.T. 60%)	Harvests 5 and 6 (L.T. 55%)	Mean
Grasses				
Panicum maximum cv. Vencedor	508	392	167	356
Brachiaria brizantha MARDI	236	514	208	319
Panicum maximum cv. Riversdale	458	286	192	312
Brachiaria humidicola	153	294	272	240
Panicum maximum cv. Rumuruti	211	300	156	222
Brachiaria dictyoneura MARDI	167	275	197	213
Setaria sphacelata cv. Splenda	300	197	58	185
Panicum maximum cv. Petrie	267	178	67	171
Setaria sphacelata cv. Kazungula	256	150	47	151
Digitaria setivalva	161	158	44	121
Mean	272	274	141	229
Legumes				
Stylosanthes scabra cv. Seca	161	200	92	151
Stylosanthes guianensis CIAT 184	139	183	128	150
Stylosanthes guianensis cv. Cook	178	172	47	132
Stylosanthes guianensis cv. Endeavour	144	178	58	127
Stylosanthes hamata cv. Amiga	217	119	19	118
Stylosanthes hamata cv. Verano	144	156	33	111
Asystasia intrusa Local	97	164	33	98
Stylosanthes capitata CPI 55843	106	94	22	74
Stylosanthes guianensis cv. Graham	136	47	28	70
Stylosanthes humilis cv. Gordon	108	72	0	60
Centrosema pubescens Local	119	22	17	53
Pueraria phaseoloides Local	50	61	33	48
Centrosema pubescens × C. macrocarpum cross MARDI	47	44	22	38
Stylosanthes humilis Commercial	81	25	6	37
Calopogonium caeruleum local	64	28	11	34
Mean	119	104	37	87

* L.T. = light transmission

Conclusions

The results presented indicate that a number of introduced species, both grasses and legumes, outyielded the local species by two- or three- fold. In selecting species for planting under rubber in Malaysia, other desirable features, besides dry matter yield should be taken into consideration. These are persistence, shade tolerance, quick ground coverage, non-competitiveness with rubber, and ability to produce seeds locally.

Since the legume species evaluated in both experiments on average recorded a yield of about half that of the grasses, it is suggested that grass–legume combinations be adopted to ensure that both adequate biomass and high quality forage is made available to animals.

The grass species which showed both high and persistent yield in the two experiments were:-

Panicum maximum cv. Riversdale, *Panicum maximum* cv. Vencedor, *Brachiaria brizantha, B. humidicola* MARDI, B. *dictyoneura* and *Paspalum notatum* CPI 11864. Other grass species which were poor–yielding but appeared to provide a vigorous low-growing cover with little weed invasion were *Paspalum wettsteinii* and *Stenotaphrum secundatum.*

The legume species which showed both high and persistent yield were:

Stylosanthes scabra cv. Seca and *Stylosanthes guianensis* CIAT 184. The *Arachis* species, although low yielding provided a good vigorous cover and indicated some potential for long term persistence at low light.

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Forage Species for Rubber Plantations in Indonesia

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Abstract

Solar radiation measurements under rubber trees showed a rapid decline in light transmission to less than two per cent of the full sunlight values from planting to 8–year–old trees. Yield of forages decreases sharply under increasing shade, with local species showing less decline than the improved tropical forages. *Asystasia intrusa* gave a higher yield under shade than other local and introduced species. Its yield was affected little by cutting frequency and its leaf proportion increased with shading level. Forage species were found to contain more nitrogen and less cell walls when grown under shade.

THE successful integration of livestock into plantations requires a continuous supply of high quality feed; however, feed supply is limited by the amount of light that penetrates the plantation canopy. Many of the volunteer species that grow under plantations contain adequate levels of protein and are consumed by livestock (Wan Mohamed 1977) although their productivity is low. Some of the traditional cover crops grown in rubber plantations have both low productivity and low palatability (Ginting et al. 1987).

This paper presents some of the research results of the forage program of the Small Ruminant Collaborative Research Support Program supported by the Agency for Agriculture Research and Development of Indonesia and USAID. The program is directed at the integration of sheep into rubber and is situated at Sei Putih in North Sumatra.

Solar Radiation Measurements

When describing forage and animal production under plantation crops it is essential to measure a range of environmental parameters and especially the amount of light reaching understorey vegetation, as this is often the main determinant of forage yield.

Photosynthetically active radiation (PAR) in the 400–700 nm band was measured instantaneously at a number of points under the trees both in full sun and under plantations at Sei Putih using a LI-COR instrument (LI-COR, Lincoln, Nebraska, USA) equipped with quantum sensors. The unit of measurement was micromoles per second per square metre (μm/sec/m^2). Typical full sun values reached just over 2000 μm/sec/m^2 by midday but varied greatly with cloud cover.

Light measurements were made under a plantation of the GT1 clone of varying age. Measurements were made between 6 trees of 2 rows at 30–minute intervals from 6.30 a.m. to 6.00 p.m. The variation in light transmission between measuring points (spatial variation) was greater at a particular time than when measurements were taken at the same points throughout a day (Table 1). It was clear that a

Table 1. Photosynthetically active radiation (PAR) measured under rubber trees of different ages and coefficients of variation (CV) among and within measuring points.

Age of trees (years)	PAR (%)	No. of samples	Coefficient of variation (%)	
			Among points[1]	Within points[2]
3	27	20	15	41
5	12	60	21	91
6	5	20	12	56
7	4	60	26	91
8	2	20	6	33
11	6	60	3	16
Average			14	55

1 Among points = CV of average daily PAR
2 Within points = CV of PAR at each time and averaged over all times

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complete set of PAR measurements for a given area over a whole day required much time and effort, and more rapid methods of PAR determination are required for routine use. This can be partially achieved by using linear sensors (larger measuring surface) and by avoiding the first and last three hours of the day when radiation levels are very low. However, in patchy shade situations, as in young plantations, quick and accurate determination of PAR will be difficult.

Production of Forages under Rubber

The main objective of the forage program at Sei Putih is to identify species which can be planted under rubber for cut-and-carry or grazing purposes. After an initial evaluation in the open of more than 50 species, 12 species of grasses, legumes and forbs were selected for a study of shade tolerance. The forages were planted in pots using both vegetative cuttings and seed. After two months, a standardisation cut was given and the pots were placed under 3, 5, 7 and 11–year–old rubber trees. One set of pots was retained in the open as a control and the pots were harvested at two-monthly intervals on three occasions from July 1989 to February 1990. Measurements of nitrogen and neutral detergent fibre (NDF) in plant tissue were also made. The fresh matter yields of the forages are presented in Table 2. Unexpectedly, most of the grasses gave higher yields under the 27% of PAR treatment than under full sun, indicating that perhaps moisture was another constraint to growth. However, at lower levels of light, yields were reduced, a trend which was greatest for the introduced species. The local species appeared to be better adapted to low light although their mean production was less than for the introduced grasses.

The legumes gave highest yields in full sun with *Clitoria ternatea* showing the greatest shade tolerance and *Stylosanthes guianensis* the highest mean yield (Table 2). The forbs similarly showed reduced yields under shade but the yield of *Asystasia intrusa* was outstanding among all the forages.

Chemical composition data showed that there was a tendency, although not statistically significant, for the nitrogen concentration in grasses and forbs to increase with shading (Table 3), a result similar to that reported by Wong et al. (1989a), Eriksen and Whitney (1981) and Wilson and Wong (1982). Legume nitrogen concentrations were not affected by shade. There was little effect of shade level on cell wall content (NDF) except for a non-significant reduction in the NDF of the forbs. There were, however, significant differences between species. In general, the legumes and forbs had higher N concentrations and lower cell wall contents than the grasses (Table 4).

Table 2. Fresh matter production measured in grams (from 5 pots) of twelve forages placed under rubber trees.

Species	PAR[1] (%)					
	100	27	8	6	3	Mean[2]
Local grasses						
Axonopus compressus	18	21	35	35	18	25[a]
Cyrtococcum oxyphyllum	21	16	15	17	10	12[a]
Paspalum conjugatum	10	54	44	29	19	31[a]
Ottochloa nodosa	22	49	17	28	6	24[a]
Introduced grasses						
Brachiaria mutica	257	188	2	2	0	90[a]
Paspalum dilatatum	255	482	29	23	0	158[ab]
Panicum maximum cv. Hamil	727	1038	169	124	9	414[c]
Legumes						
Centrosema pubescens	105	99	13	26	4	49[a]
Clitoria ternatea	244	96	80	49	25	99[ab]
Stylosanthes guianensis	1479	457	0	16	–	391[c]
Forbs						
Mikania cordata	602	629	42	62	9	269[bc]
Asystasia intrusa	1593	611	519	123	167	603[d]

[1] Photosynthetically active radiation
[2] Values with different superscripts are significantly different ($p < 0.01$).

Table 3. Influence of fractional levels of photosynthetically active reduction (PAR) on the nitrogen concentrations and cell wall content of some grasses, legumes and forbs grown under rubber.

Species	PAR (%)				
	100	27	8	6	3
Local grasses					
N (%)	1.76	1.71	1.95	2.31	2.02
NDF (%)	68.3	65.0	64.6	62.8	63.6
Introduced grasses					
N (%)	1.54	1.58	1.78	1.63	1.55
NDF (%)	66.4	65.1	67.7	65.7	73.3
Legumes					
N (%)	2.91	2.55	2.83	2.68	2.08
NDF (%)	55.5	59.5	57.6	59.9	59.3
Forbs					
N (%)	1.99	2.70	2.70	2.43	2.83
NDF (%)	59.4	46.7	46.5	51.4	45.9

Table 4. Nitrogen concentrations and cell wall content of some grasses, legumes and forbs grown under rubber.

Species	N concentration (%)	Cell wall content (%)
Local grasses		
Axonopus compressus	1.95^{ab}	66.5^{ef}
Cyrtococcum oxyphylum	2.04^{ab}	66.7^{ef}
Paspalum conjugatum	1.73^{ab}	63.5^{efd}
Ottochloa nodosa	2.02^{ab}	62.7^{efd}
Introduced grasses		
Brachiaria mutica	1.72^{ab}	67.9^{ef}
Paspalum dilatatum	1.68^{a}	62.3^{efd}
Panicum maximum cv. Hamil	1.52^{a}	69.9^{f}
Legumes		
Centrosema pubescens	3.24^{d}	61.4^{ecd}
Clitoria ternatea	2.68^{c}	58.6^{bcd}
Stylosanthes guianensis	2.39^{bc}	54.0^{abc}
Forbs		
Mikania cordata	2.26^{bc}	53.6^{ab}
Asystasia intrusa	2.77^{de}	47.1^{a}

Means followed by different superscripts are statistically significantly different ($P<0.01$)

Although this pot technique was useful to compare the response of species to varying light regimes with other environmental factors controlled, it may be less relevant when comparing species of differing growth habit such as creeping versus erect types.

Yield of *Asystasia intrusa* under Cutting

In view of the good performance of *Asystasia intrusa* in the first experiment and its known palatability (Mokhtar and Wong 1988, Wong et al. 1989b), a second pot experiment was established under the same range of plantation ages to investigate the yield potential of this species under 2, 4, 6 and 8-week cutting frequencies. The experiment was conducted over a four-month period from December 1989 to May 1990. Fresh matter yields were not significantly affected by cutting interval and there was an average 30% decrease in yield at lower light transmission levels.

Conclusions

There is clearly a need for a reliable and rapid technique for measurement of light penetration in plantations. Measurements at midday, corrected to obtain whole day radiation, may be a solution.

Further research should be conducted on *Asystasia intrusa* since it shows remarkable shade tolerance, good nutritive value, high palatability and excellent seed production for establishment and self-propagation. The main concerns over the use of *Asystasia* are its potential to compete with rubber for nutrients and the danger of its becoming a dominant weed in new environments.

The search for other shade-tolerant species adapted to light levels below 30% PAR should be continued among grasses, legumes and other plants. The main criteria of selection should be production under shade, persistence under grazing or cutting, good palatability and minimal competition with the main plantation crops.

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Screening Forage Species for Shade Tolerance - A Preliminary Report

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Abstract

A total of 130 grass and legume accessions, many originally collected in shaded habitats, were grown in small plots at the University of Queensland research farm at Redland Bay. Light transmission levels of 100, 70, 50, 35 and 20% were imposed and plots were harvested every 6 weeks to study the yield potential and shade tolerance of the species.

A number of grass and legume accessions were identified which exhibited shade tolerance. Many of these accessions have not previously been used and need to be tested under plantation crops.

Variability in shade tolerance exists between species of the same genus and between accessions of the same species.

THE term shade tolerance is used extensively in discussions on forages for plantation crops. It is normally used to describe those species which grow relatively better than other species in shaded habitats, such as plantations. A common characteristic is that they are better able to maintain their yield with decreasing light than less shade-tolerant species.

Forage species which are successful in plantation crops must be adapted not only to the lower light level but also to the climate (rainfall, temperature, daylength variation), soil (pH, fertility, texture, drainage) and to the management imposed (cutting or grazing regime, fertilizer inputs). Shade tolerance is therefore confounded with these other factors and this may make the interpretation of field results of shading experiments more difficult.

The significance of shade tolerance to the persistence and yield of species under plantation crops varies with shading level. In open pastures, Ludlow (1978) concluded that shade tolerance plays only a minor role in the competition for light between pasture plants, while the ability to gain access to the available light is of prime importance. On the other hand, the significance of shade tolerance increases at lower light levels.

Competition for light between companion forages is primarily determined by plant height as this determines the position of the species in relation to its competitors (Ludlow, 1978). Hence, elongation of stem at low light is a commonly observed response of non–shade–tolerant species. While this response is advantageous in high light environments, it can be very costly to plants competing in low light environments. There, efficient light capture and use are of utmost importance, particularly under repeated defoliation regimes. There are many instances where forages have yielded well initially in low light but failed to persist under regular cutting or grazing (e.g. Wong et al. 1985, Watson and Whiteman 1981). True shade tolerance in forage species is associated with a number of morphological and physiological adaptations of plants. These include higher leaf area ratios and specific leaf areas, and higher chlorophyll densities which in turn influence the efficiency of interception and use of radiation and therefore growth potential at low levels of radiation.

The purpose of this study was to identify shade tolerance in a wide range of accessions of grasses and legumes which were being concurrently evaluated in adaptation studies under coconuts and rubber in Indonesia and Malaysia respectively (Rika et al.; Kaligis and Sumolang; Ng, these Proceedings).

Materials and Methods

A total of 130 grass and legume accessions were included in the experiment. Most of these were obtained from R.J. Williams, Australian Tropical Forages Genetic Resource Centre, CSIRO. Wherever possible, accessions selected were those which had been collected originally from shaded habitats or had demonstrated a degree of shade tolerance.

The accessions were grown in small plots (0.5 × 0.5 m), each containing nine plants, at the

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University of Queensland research station at Redland Bay. There were five light levels (100, 70, 50, 35 and 20 %), which were achieved with shade cloth, and two replicates.

Accessions were germinated, inoculated where appropriate, and grown in small pots in a glasshouse. Vegetative material was multiplied at the same time. Seedlings (or young plants) were transplanted into the field at Redland Bay in early December 1988 and plots were then harvested every six weeks for three growth cycles. Fertilizer was applied at a rate of 65 kg/ha P and 50 kg/ha K before planting. Nitrogen was applied to the grasses only at a rate of 20 kg/ha per growth cycle. The experimental area was irrigated whenever necessary to avoid water deficits. Cutting height varied according to the growth habit of each species. Top dry weight of whole plots was measured at each harvest.

The experiment continued into the second year but, at the time of the workshop, data were available for the first year only. For analysis, data were averaged across all harvests.

Results and Discussion

In this paper, the results are expressed in two ways. Firstly, species were ranked in order of their yield at a particular light level and, secondly, their yield at a particular light level was expressed as percentage of their yield at high light; this was called relative yield. The combination of yield at a particular light level and relative yield was considered to be a measure of shade tolerance. High light was defined as the mean of the yield of the 100 and 70% light transmission treatments. The average of these two treatments was chosen to increase the precision of the relative yield calculation.

The yield and the relative yield of the 30 highest-yielding accessions is presented for the 50% and 20% light transmission treatments (Tables 1 and 2). The 50% treatment approximates the light level experienced in coconut plantations, while the 20% light transmission treatment is similar to the light level in mature rubber plantations. The tables also show the relative yield ranking of each species relative to all 46 grasses and 84 legumes in the experiment, not just those species presented in the tables.

At 50% light transmission, many of the commercially used tropical pasture grasses such as the *Panicum maximum* cultivars had the highest dry matter yields (Table 1). These were tall, upright species which would be expected to have high yields in full sun. The highest-yielding species of the lower growing grasses was *Paspalum wettsteinii*. Grasses with an above average yield (>166 g) and an above-average relative yield (>68%) were *Paspalum malacophyllum*, *Urochloa stolonifera*, *Paspalum wettsteinii*, *Digitaria natalensis* and *Paspalum conjugatum*. With the exception of *Paspalum conjugatum*, these species have not been widely used under coconuts. While the importance of relative yield is equivocal, the species with the highest relative yields (i.e. *Axonopus compressus* and *Paspalum conjugatum*) are known to be shade-tolerant pasture grasses and successful in coconut plantations (Shelton et al. 1987, Reynolds 1988).

As with the grasses, at 50% light transmission the highest-yielding legumes tended to be the more upright species such as *Aeschynomene americana*, *Desmodium intortum* and *Mucuna* sp. (Table 1). All of the 30 legume species listed in Table 1 had a higher than average yield (>47 g) and many also had a higher than average relative yield (>60%). The five highest-yielding species were *Aeschynomene americana* cv. Glenn, *Desmodium intortum* cv. Greenleaf, *Vigna luteola* cv. Dalrymple, *Stylosanthes humilis* cv. Gordon and *Stylosanthes humilis* (commercial). *Stylosanthes guianensis* cultivars have been regarded as having a low shade tolerance (Shelton et al. 1987) but it appears that variation in shade tolerance exists between species of the same genus. Other legumes with a relative yield of more than 80% included *Rynchosia minima*, *Centrosema macrocarpum* and *Desmodium heterophyllum* cv. Johnstone. Of these species, *Desmodium heterophyllum* is known to be a shade-tolerant species (Shelton et al. 1987).

The yield ranking of grasses at 20% light transmission was similar to the yield ranking at 50% light transmission. The *Panicum maximum* cultivars remained the highest-yielding grasses at this low light level (Table 2). Species which improved their yield ranking substantially were *Brachiaria humidicola* cv. Tully, *Dichanthium aristatum* cv. Angleton, *Axonopus compressus*, *Digitaria pentzii* CPI 59772 and *Acroceras macrum*. Of the grasses with an above-average yield only *Brachiaria humidicola* cv. Tully, *Paspalum malacophyllum*, *Digitaria milanjiana* CPI 41192 and *Axonopus compressus* had a higher than average relative yield. Grasses which had a substantially lower relative yield at 20% than at 50% light transmission were *Setaria sphacelata* cv. Kazungula, *Setaria sphacelata* cv. Splenda and *Urochloa stolonifera*.

The yield ranking of legumes changed to a greater extent than that of the grasses as light transmission was reduced from 50 to 20% (Table 2). Legumes which had a much lower yield ranking at 20 than at 50% light transmission included *Aeschynomene americana* cv. Glenn, *Aeschynomene americana* CPI 56283, *Stylosanthes humilis* cv. Gordon and *Stylosanthes humilis* (commercial) indicating low tolerance of heavy shade. Conversely, accessions which improved their yield ranking by 20 ranks or more were *Arachis pintoi* cv. Amarillo, *Desmodium heterophyllum* CPI 52420, *Desmodium gangeticum*, *Centrosema pascuorum*, *Neonotonia wightii* cv. Tinaroo, *Teramnus labialis* cv.

Table 1. Dry matter yield of forages grown at 50% light (g/plot) and their yield at 50% light relative to their mean yield at 100 and 70% light (%) - the 30 highest yielding accessions.

Species	Dry matter yield at 50% light		Yield at 50% light relative to mean yield at 100 and 70% light	
	(g/plot)	Rank	(%)	Rank
Grasses				
Panicum maximum cv. Rumuruti	498	(1)	53	(37)
Panicum maximum cv. Riversdale	461	(2)	65	(19)
Panicum maximum cv. Petrie	454	(3)	66	(17)
Panicum maximum cv. Gatton	430	(4)	57	(33)
Urochloa mosambicensis CPI 60148	340	(5)	62	(23)
Setaria sphacelata cv. Kazungula	325	(6)	68	(15)
Panicum maximum cv. Embu	298	(7)	62	(23)
Setaria sphacelata cv. Splenda	283	(8)	59	(29)
Brachiaria decumbens cv. Basilisk	244	(9)	55	(34)
Paspalum malacophyllum CPI 27690	218	(10)	97	(6)
Digitaria milanjiana CPI 59721	211	(11)	61	(25)
Urochloa stolonifera CPI 47173	197	(12)	69	(14)
Paspalum wettsteinii (commercial)	189	(13)	94	(8)
Digitaria endlichii CPI 59768	188	(14)	45	(42)
Digitaria natalensis CPI 59689	183	(15)	86	(10)
Brachiaria brizantha CPI 15890	181	(16)	58	(31)
Digitaria milanjiana CPI 59748	177	(17)	60	(27)
Paspalum conjugatum CPI 60059	166	(18)	126	(2)
Digitaria swynnertonii CPI 59749	159	(19)	66	(17)
Paspalum scrobiculatum cv. Paltridge	156	(20)	74	(12)
Digitaria milanjiana CPI 59773	146	(21)	60	(27)
Digitaria milanjiana CPI 41192	144	(22)	65	(19)
Paspalum commersonii CPI 15705	142	(23)	65	(19)
Paspalum plicatulum cv. Bryan	141	(24)	54	(36)
Digitaria pentzii CPI 41190	139	(25)	65	(19)
Paspalum dilatatum (commercial)	137	(26)	100	(5)
Brachiaria humidicola cv. Tully	133	(27)	52	(38)
Digitaria milanjiana CPI 59775	122	(28)	55	(34)
Axonopus compressus (local) Brisbane	120	(29)	150	(1)
Paspalum notatum cv. Competidor	89	(30)	95	(7)
Mean of 46 grasses	**166**		**68**	
Legumes				
Aeschynomene americana cv. Glenn	143	(1)	62	(39)
Aeschynomene americana CPI 56283	125	(2)	45	(70)
Desmodium intortum cv. Greenleaf	102	(3)	63	(36)
Mucuna sp. CPI 11843	96	(4)	58	(49)
Vigna luteola cv. Dalrymple	94	(5)	63	(36)
Aeschynomene americana CPI 70244	92	(6)	53	(58)
Desmodium intortum (Grp J) CPI 46552	89	(7)	55	(50)
Stylosanthes humilis cv. Gordon	80	(8)	82	(6)
Stylosanthes humilis (commercial)	78	(9)	68	(24)
Desmodium intortum (Grp C) CPI 43201	78	(9)	54	(54)
Calopogonium mucunoides CPI 58541	74	(11)	76	(10)
Cassia rotundifolia CPI 10057	72	(12)	68	(24)
Rynchosia minima CPI 87555	70	(13)	84	(5)
Vigna hosei CQ 729	66	(14)	67	(26)
Stylosanthes guianensis cv. Endeavour	65	(15)	54	(54)
Stylosanthes hamata cv. Amiga	63	(16)	45	(70)
Centrosema macrocarpum CPI 92731	63	(16)	91	(3)
Calopogonium mucunoides (commercial)	63	(16)	70	(21)
Vigna lasiocarpa (Grp A) CPI 34436	62	(19)	60	(43)

Table 1. *(Continued)*

Species	Dry matter yield at 50% light		Yield at 50% light relative to mean yield at 100 and 70% light	
	(g/plot)	Rank	(%)	Rank
Macroptilium atropurpureum cv. Siratro	62	(19)	61	(41)
Stylosanthes hamata cv. Verano	60	(21)	47	(65)
Desmodium scorpiurus CPI 108338	60	(21)	74	(12)
Cassia rotundifolia CPI 85836	60	(21)	48	(62)
Desmodium aparine CPI 33814	57	(24)	55	(50)
Clitoria ternatea CPI 52395	57	(24)	51	(60)
Stylosanthes guianensis cv. Graham	56	(26)	52	(59)
Centrosema plumieri CPI 58568	55	(27)	65	(32)
Neonotonia wightii cv. Malawi	54	(28)	63	(36)
Macroptilium atropurpureum CPI 94058	54	(28)	64	(34)
Desmodium heterophyllum cv. Johnstone	54	(28)	82	(6)
Centrosema pubescens (common)	54	(28)	73	(14)
Mean of 84 legumes	**47**		**60**	

Table 2. Dry matter yield of forages grown at 20% light (g/plot) and the yield at that light level relative to the mean yield at 100 and 70% light (%) – the 30 highest yielding accessions.

Species	Dry matter yield at 20% light		Yield at 20% light relative to mean yield at 100 and 70% light	
	(g/plot)	Rank	(%)	Rank
Grasses				
Panicum maximum cv. Petrie	128	(1)	19	(19)
Panicum maximum cv. Rumuruti	127	(2)	14	(35)
Panicum maximum cv. Gatton	126	(3)	17	(25)
Panicum maximum cv. Riversdale	125	(4)	18	(21)
Panicum maximum cv. Embu	98	(5)	20	(17)
Urochloa mosambicensis CPI 60148	85	(6)	16	(29)
Setaria sphacelata cv. Kazungula	77	(7)	16	(29)
Brachiaria humidicola cv. Tully	76	(8)	30	(7)
Setaria sphacelata cv. Splenda	62	(9)	13	(38)
Paspalum malacophyllum CPI 27690	59	(10)	26	(10)
Brachiaria decumbens cv. Basilisk	59	(10)	13	(38)
Digitaria endlichii CPI 59768	57	(12)	13	(38)
Digitaria milanjiana CPI 41192	56	(13)	25	(11)
Dichanthium aristatum cv. Angleton	50	(14)	21	(15)
Axonopus compressus (local) Brisbane	50	(14)	62	(1)
Urochloa stolonifera CPI 47173	49	(16)	17	(25)
Digitaria milanjiana CPI 59773	45	(17)	18	(21)
Paspalum wettsteinii (commercial)	44	(18)	22	(13)
Paspalum conjugatum CPI 60059	44	(18)	34	(5)
Digitaria milanjiana CPI 59748	44	(18)	15	(32)
Digitaria milanjiana CPI 59721	41	(21)	12	(41)
Paspalum plicatulum cv. Bryan	38	(22)	15	(32)
Paspalum dilatatum (commercial)	38	(22)	27	(8)
Digitaria pentzii CPI 59772	38	(22)	19	(19)
Digitaria milanjiana CPI 59775	38	(22)	17	(25)
Acroceras macrum CPI 62122	38	(22)	34	(5)
Brachiaria brizantha CPI 15890	37	(27)	12	(41)
Digitaria swynnertonii CPI 59749	36	(28)	15	(32)
Digitaria pentzii CPI 41190	35	(29)	17	(25)
Paspalum scrobiculatum cv. Paltridge	33	(30)	16	(29)
Mean of 46 grasses	**47**		**21**	

Species	Dry matter yield at 20% light (g/plot)	Rank	Yield at 20% light relative to mean yield at 100 and 70% light (%)	Rank
Legumes				
Desmodium intortum cv. Greenleaf	56	(1)	34	(7)
Mucuna sp. CPI 11843	39	(2)	24	(26)
Vigna luteola cv. Dalrymple	38	(3)	26	(21)
Desmodium intortum (Grp J) CPI 46552	36	(4)	22	(38)
Macroptilium atropurpureum cv. Siratro	35	(5)	35	(5)
Aeschynomene americana CPI 70244	29	(6)	17	(57)
Vigna hosei CQ 729	28	(7)	28	(15)
Calopogonium mucunoides (commercial)	28	(7)	31	(10)
Arachis pintoi cv. Amarillo	27	(9)	48	(1)
Desmodium intortum (Grp C) CPI 43201	26	(10)	18	(53)
Desmodium heterophyllum (Grp B) CPI 52420	25	(11)	33	(8)
Centrosema plumieri CPI 58568	25	(11)	30	(13)
Vigna lasiocarpa (Grp A) CPI 34436	24	(13)	23	(32)
Desmodium aparine CPI 33814	24	(13)	23	(32)
Centrosema pubescens (common)	24	(13)	32	(9)
Calopogonium mucunoides CPI 58541	24	(13)	25	(23)
Desmodium heterophyllum cv. Johnstone	21	(17)	31	(10)
Clitoria ternatea CPI 52395	21	(17)	18	(53)
Cassia rotundifolia CPI 85836	21	(17)	17	(57)
Aeschynomene americana cv. Glenn	21	(17)	9	(75)
Desmodium gangeticum CPI 105779	20	(21)	30	(13)
Centrosema pascuorum CPI 40060	20	(21)	18	(53)
Desmodium scorpiurus CPI 108338	19	(23)	23	(32)
Aeschynomene americana CPI 56283	19	(23)	17	(57)
Neonotonia wightii cv. Malawi	18	(25)	21	(41)
Neonotonia wightii cv. Tinaroo	18	(25)	23	(32)
Centrosema pubescens CPI 97066	18	(25)	24	(26)
Cassia rotundifolia cv. Wynn	18	(25)	20	(45)
Teramnus labialis cv. Semilla Clara	17	(29)	27	(18)
Pueraria phaseoloides (commercial)	17	(29)	22	(38)
Macrotyloma axillare cv. Archer (Grp A)	17	(29)	17	(57)
Macroptilium atropurpureum CPI 94058	17	(29)	20	(45)
Desmodium heterocarpon cv. Florida	17	(29)	27	(18)
Mean of 84 legumes	**16**		**22**	

Semilla Clara and *Desmodium heterocarpon* cv. Florida. Many of the legumes with an above-average yield also had an above-average relative yield. The ten legumes with the highest relative yields and above-average absolute yields were *Desmodium intortum* cv. Greenleaf, *Macroptilium atropurpureum* cv. Siratro, *Calopogonium mucunoides, Arachis pintoi* cv. Amarillo, *Desmodium heterophyllum* CPI 52420, *Centrosema pubescens* (common) and *Desmodium heterophyllum* cv. Johnstone.

Conclusions

The experiment has identified a number of grass and legume accessions which have shown a high yielding capacity at 50 and 20% light transmission, and many of these also had a high relative yield. These species can be regarded as being shade tolerant. Most of these accessions have not previously been used and need to be tested under plantation crops. Selection of accessions will need to take into account particular environmental conditions and the proposed management of the species.

A large variability was apparent between species of the same genus and there were also differences between accessions of the same species.

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Shade Tolerance of Tropical Forages: A Review

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Abstract

The paper reviews the shade tolerance of tropical forages and discusses the adaptation of species to low light. Shading reduces tiller production and leaf, stem, stubble and root yield but increases specific leaf area and shoot/root and leaf/stem ratios, particularly in shade-tolerant species. Yield responses of many tropical forages to shading reflected the strong relationship between productivity and irradiance, but was often confounded with nitrogen availability.

There is potential for improvement of forage productivity in light to moderate shade but less in dense shade where yields of both high-yielding shade-intolerant plants and low-yielding shade-tolerant plants are similar and low. However, the ability of shade-tolerant plants to persist under shade and regular defoliation may be of greater importance for long-term productivity. A number of species suitable for various shade environments is reported. Species suitable for light to moderate shade are *Brachiaria decumbens*, *Brachiaria brizantha*, *Panicum maximum*, *Centrosema pubescens*, *Desmodium intortum* cv. Greenleaf, *Leucaena leucocephala*, *Calopogonium caeruleum*, *Pueraria phaseoloides* and *Desmodium ovalifolium*. In dense shade (<30% sunlight) *Axonopus compressus*, *Brachiaria miliiformis*, *Paspalum conjugatum* and *Stenotaphrum secundatum* persisted well but had a low productivity. The significance of persistence in shade-tolerant forages for long-term productivity in dense shade was emphasised.

THE plantation crops of southeast Asia and the South Pacific cover an extensive area, including at least 5 million ha of coconut plantation in Indonesia, Philippines and South Pacific islands, and another 2.8 million ha of rubber and oil palm in Malaysia (Rika 1985). These plantation lands with their understorey forages represent one of the most extensive and underutilised feed resources in the region.

The major constraint in the exploitation of these plantation lands for forage and ruminant production is the fast-changing light environment below the plantation canopy over time. Shade-tolerant species are needed to improve and sustain production. This paper reviews both indigenous and improved tropical forages for their shade tolerance and forage productivity in plantation crops.

Shade Tolerance

Currently, there is no acceptable definition of shade tolerance but it may best be defined, agronomically, as the relative growth performance of plants in shade compared to that in full sunlight as influenced by regular defoliation. It embodies the attributes of both dry matter (DM) productivity and persistence. The reported shade tolerance of some common tropical forages is illustrated in Table 1.

Morphological Adaptation

Shade affects the growth and morphological development of plants. Tiller production and leaf, stem, stubble, and root production are often reduced at low light with formation of thinner leaves with higher water content and a higher specific leaf area (Wong et al. 1985a,b). The increased partitioning of DM to the leaf component at the expense of root often results in higher shoot/root, leaf/stem, leaf weight and leaf area ratios, especially in grasses (Table 2). Grasses with high shade tolerance were found to have a higher specific leaf area and leaf area ratio than those with low shade tolerance (Table 3). The same trend was to a lesser extent observed with legumes (Table 3).

Morphological acclimatisation of forages to light attenuation is an adaptive strategy to compensate, at least partially, for the lower photosynthetic rate per unit leaf area. In addition, chemical changes may also occur under low light to enhance photosynthetic efficiency. Foliar nitrogen has been shown to increase in shaded grasses but not in shaded legumes (Wong and Wilson 1980; Samarakoon 1987). Higher nitrogen concentrations in grass leaves was associated with enhanced efficiency of conversion of radiant energy

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Table 1. Shade tolerance of some important tropical forages.

Shade tolerance	Grasses	Legumes
High	*Axonopus compressus* *Brachiaria miliiformis* *Ischaemum aristatum* *Ottochloa nodosa* *Paspalum conjugatum* *Stenotaphrum secundatum*	*Calopogonium caeruleum* *Desmodium heterophyllum* *Desmodium ovalifolium* *Flemengia congesta*
Medium	*Brachiaria brizantha* *Brachiaria decumbens* *Brachiaria humidicola* *Digitaria setivalva* *Imperata cylindrica* *Panicum maximum* *Pennisetum purpureum* *Setaria sphacelata*	*Calopogonium mucunoides* *Centrosema pubescens* *Desmodium triflorum* *Pueraria phaseoloides* *Desmodium intortum* *Leucaena leucocephala*
Low	*Brachiaria mutica* *Cynodon plectostachyus* *Digitaria decumbens* *Digitaria pentzii*	*Stylosanthes hamata* *Stylosanthes guianensis* *Zornia diphylla* *Macroptilium atropurpureum*

Source: adapted and modified from Shelton et al. 1987, Reynolds 1978, Eriksen and Whitney 1982, Chen and Bong 1983, and Wong et al. 1985b.

Table 2. Growth characteristics of tropical grasses and legumes grown at four light levels (mean of 12 species).

Light level (% PAR)	Tillers (no./pot)	LWR	LAR (cm^2/g)	Leaf/Stem ratio	Shoot/root ratio	SLA (cm^2/g)	Foliar nitrogen (%)
Grasses							
100	132	0.32	0.4	1.1	2.5	170	1.44
56	92	0.38	0.6	1.2	3.8	227	1.74
34	63	0.49	1.2	1.6	7.1	332	2.07
18	27	0.51	1.3	1.8	6.7	354	2.33
Legumes							
100	153	0.47	1.1	1.2	6.5	227	3.46
56	132	0.48	1.5	1.2	8.6	301	3.52
34	53	0.49	1.9	1.2	14.9	378	3.81
18	36	0.50	2.0	1.2	14.2	391	3.78

LWR = leaf weight ratio, LAR = leaf area ratio, SLA = specific leaf area

(Sophanodora 1989). On the other hand, nodulation in shaded legumes was adversely affected and nodule numbers declined with increasing shade intensity, and this may explain the contrasting response in legumes.

Yield Response to Shade

Shade imposes a limitation to biological productivity in plants although the extent of the limitation varies with shade tolerance of the species and the nitrogen supply.

Eriksen and Whitney (1981) found that in high-yielding grass species, well supplied with nitrogen, yield increased almost linearly with increasing light up to 75% of full sun, and then tended to plateau as light transmission increased to 100% of full sun (Table 4). At low nitrogen, yield of the same species maximised at lower light levels. Wong et al. (1985a) obtained similar results with high-yielding species well supplied with nitrogen, indicating that light was not the only factor controlling yield. Nevertheless, for species reputed to be shade-tolerant (*Axonopus compressus* and *Paspalum conjugatum*) (Table 2), yield maximised at much lower

Table 3. Percentage composition of plant parts, specific leaf area and leaf area ratio of some tropical forages grown in shade (mean of 64, 30, 18 and 9% light transmission).

Species	Composition (% of DM)			SLA cm^2/g	LAR cm^2/g
	Root	Stem	Leaf		
High shade tolerance					
Paspalum conjugatum	13	47	40	342	1.1
Axonopus compressus	24	30	46	296	1.2
Desmodium ovalifolium	11	37	52	437	2.3
Calopogonium caeruleum	12	35	53	407	2.2
Medium shade tolerance					
Panicum maximum	21	28	52	211	0.8
Digitaria setivalva	21	24	56	248	0.6
Centrosema pubescens	13	37	50	388	2.0
Low shade tolerance					
Digitaria decumbens cv. Transvale	13	5	30	176	0.4
Stylosanthes guianensis cv. Schofield	8	49	43	284	1.2
Stylosanthes hamata cv. Verano	12	41	48	222	1.7

SLA = specific leaf area, LAR = leaf area ratio
Source: Wong et al. 1985a,b

light levels (Table 4). It can be concluded from these data that both potentially high-yielding species, which are limited by nitrogen availability, and low-yielding shade-tolerant species, are light-saturated at low levels of solar radiation.

An unusual effect of shade on growth of grasses has been reported by Wilson et al. (1990). The DM and nitrogen yield of a *Paspalum notatum* pasture was higher under a *Eucalyptus grandis* plantation than in the adjacent full sun area. The authors suggested that shade may have had a positive effect on the availability of soil nitrogen (Wilson et al. 1990).

Legumes behaved differently in the studies by Wong et al. (1985b) and Eriksen and Whitney (1982) (Table 4). While in the experiment by Eriksen and Whitney (1982) the response of legume yield to light transmission was close to linear, most species showed maximum yield at low light level in the experiment by Wong et al. (1985). No clear response patterns can therefore be claimed.

For both grasses and legumes, species differences were greater under moderate to high light transmission than under low light. The low yield potential of all species in low light remains a major constraint to forage productivity in plantations which close their canopies with age. However, in plantations with open canopies such as coconut, species with medium shade tolerance can be exploited to obtain higher yields.

The most productive species for moderate shade, from the work of Wong et al. (1985b) and Eriksen and Whitney (1982), were *Panicum maximum, Brachiaria brizantha, Brachiaria decumbens* and *Desmodium intortum*. For low light environments, the more shade-tolerant species *Axonopus compressus* and *Paspalum conjugatum* were not highly productive but were persistent.

The productivity of some promising forages grown under natural plantation shade is shown in Table 5. It is in the dense shade that productivity of shade-tolerant species has been disappointing. At light levels of less than 25% sunlight, there appears to be no superiority of any particular forage. Many introduced species died out in dense shade (Chen and Bong 1983; Chen and Othman 1984) and weed invasion was often as high (Mohd Najib 1989; Wong et al. 1988). The potential to use improved pastures at such low light levels to increase forage production therefore remains doubtful (Wilson 1988).

Persistence

However, an important character in the selection of shade-tolerant species is their ability to persist and compete with the shade-tolerant weeds under continual defoliation or herbivory. The term persistence includes both the survival of individual plants (longevity and vegetative propagation) and seedling replacement. Indigenous shade species such as *A. compressus, S. secundatum, B. miliiformis* and *P. conjugatum* have been the most persistent and productive under low light levels. Any new shade-tolerant genotypes that are identified must be able to out-perform these species in dense shade.

Table 4. Productivity (DM t/ha/yr) of some tropical forages in pure swards under artificial shade of varying irradiance.

Species	Shade level (% sunlight)				Reference
	18–27	34–45	60–70	100	
(a) Grasses					
0 N/ha/yr					
Brachiaria brizantha	12	13	12	13	Eriksen and Whitney (1981)
Brachiaria miliiformis	9	8	7	4	
Digitaria decumbens	6	14	10	9	
Panicum maximum	13	15	12	9	
Pennisetum clandestinum	5	9	9	4	
365 kg N/ha/yr					
Brachiaria brizantha	15	21	30	29	Eriksen and Whitney (1981)
Brachiaria miliiformis	14	20	24	18	
Digitaria decumbens	10	20	25	29	
Panicum maximum	14	24	32	30	
Pennisetum clandestinum	8	10	20	16	
150 kg N/ha/yr					
Axonopus compressus	3	8	7	4	Wong et al. (1985a)
Brachiaria decumbens	8	13	16	23	
Panicum maximum	8	16	16	22	
Setaria sphacelata cv. Kazungula	6	10	14	12	
Paspalum conjugatum	3	4	4	4	
(b) Legumes					
Calopogonium caeruleum	2	4	4	3	Wong et al. (1985b)
Centrosema pubescens	1	2	2	4	
Desmodium ovalifolium	4	5	5	4	
Stylosanthes guianensis cv. Endeavour	5	7	9	15	
Pueraria phaseoloidies	2	3	3	4	
Desmodium intortum cv. Greenleaf	9	15	19	20	Eriksen and Whitney (1982)
Centrosema pubescens	6	9	12	14	
Macroptilium atropurpureum	3	5	9	13	
Stylosanthes guianensis cv. Schofield	3	5	12	17	

Persistence of forages is affected not only by their tolerance to shading but also by their ability to tolerate regular defoliation. A longer cutting interval has enhanced persistence of a number of grasses grown under the closed canopy of oil palms (Table 6). The shade-tolerant species *Axonopus compressus* and *Paspalum conjugatum* (Table 1) had a higher plant density at the end of the experiment than at the beginning, while less shade-tolerant grasses persisted poorly. This may have been related to either poor shade tolerance or damage from pests and fungal diseases in dense shade. The persistence of legumes under the closed canopy of oil palms was, with the exception of *Calopogonium mucunoides*, generally poor in a trial reported by Chen and Othman (1984).

In other trials the sown grasses and legumes *Brachiaria decumbens, Brachiaria mutica, Brachiaria humidicola, Centrosema pubescens* and *Calopogonium mucunoides* did not persist under regular grazing (Chen et al. 1978, Smith and Whiteman 1985). Ultimately they were replaced by naturalised species of lower productivity.

Identification of characteristics of shade-tolerant species, that render them persistent under frequent defoliation, may help our understanding of stability of forages in integrated plantation production systems and lead to more rational species evaluation procedures for shade tolerance.

Conclusions

The performance of tropical forages under shade, including shade-tolerant species such as *Axonopus compressus, Paspalum conjugatum, Desmodium heterophyllum* and *Stenotaphrum secundatum*, is poor in low light (<25% of full sunlight). There is a need for more productive shade-tolerant species.

At higher light levels such as in mature coconut plantations (50-80% light transmission), and during the early establishment of rubber and oil palm plantations, improved tropical grasses and legumes,

Table 5. Productivity (DM t/ha/yr) of some tropical forages in pure swards grown under the natural shade of plantation crops.

Species	Shade as % sunlight 0–25%	26–50%	51–75%	76–100%	Reference
Coconut					
Brachiaria decumbens	0.7	4.4	9-11	28	Smith and Whiteman (1983)
Brachiaria humidicola	0.7	4.1	9-12	22	
Brachiaria miliiformis	1.0	3.4	4-7	18	
Stenotaphrum secundatum	1.9	4.9	3-4	6	
Axonopus compressus	1.3	1.9	4-5	5	
Paspalum conjugatum	1.0	2.6	2	8	
Ischaemum aristatum	.03	5.5	7-8	14	
Stylosanthes guianensis	–	–	–	15.2	Steel and Humphreys (1974)
Centrosema pubescens	–	–	–	3.3	
Panicum maximum (tall)	–	–	15.5	–	Reynolds (1978)
Brachiaria humidicola	–	–	10.5	–	
Brachiaria brizantha	–	–	8.9	–	
Brachiaria miliiformis	–	–	8.2	–	
Paspalum conjugatum	–	–	8.5	–	
Brachiaria brizantha	–	–	5-11	–	Manidool (1984)
Axonopus compressus	–	–	4-7	–	
Paspalum conjugatum	–	–	4-7	–	
Panicum maximum	–	–	1	–	
Rubber					
Brachiaria miliiformis	1.2	4.3	8.4	8.8	Waidyanatha et al. (1984)
Panicum maximum	2.2	6.1	8.9	11.1	
Brachiaria brizantha	2.1	5.6	8.6	10.1	
Panicum maximum	3.5	–	8.5	14.5	Mohd Najib (1989)
Pennisetum purpureum	4.2	–	9.5	12.3	
Oil Palm					
Panicum maximum	1.0	–	–	–	Chen and Bong (1983)
Axonopus compressus	.9	–	–	–	
Paspalum conjugatum	1.0	–	–	–	
Setaria sphacelata	0.6	–	–	–	
Digitaria setivalva	1.0	–	–	–	
Brachiaria decumbens	1.7	–	–	–	
Desmodium ovalifolium	2.0	–	–	–	Chen and Othman (1984)
Calopogonium caeruleum	0.6	–	–	–	
Centrosema pubescens	0.4	–	–	–	
Stylosanthes guianensis	0.3	–	–	–	
Desmodium heterophyllum	0.3	–	–	–	

[a] estimated

particularly *Panicum*, and *Brachiaria* and *Desmodium*, have the potential to improve forage supply.

The declining DM yield with decreasing light levels and the increased sensitivity of shaded grasses to defoliation necessitate proper management to ensure high productivity and persistence in a rapidly changing light environment. Persistent shade-tolerant species are needed for the long-term productivity and economic viability of integrated land-use systems.

Species that show high productivity and forage quality in a wide range of light levels (90 to 20% of full sunlight) are desirable but are presently not available.

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Table 6. Persistence (expressed as % of initial plant density) of some tropical grasses as affected by defoliation frequency under the closed canopy of oil palm.

	Cutting interval (weeks)			
	8	12	16	Mean persistence
High shade tolerance				
Paspalum conjugatum	172	156	510	279
Axonopus compressus	594	557	323	491
Medium shade tolerance				
Panicum maximum	6	3	20	10
Digitaria setivalva	2	42	67	37
Brachiaria decumbens	4	44	56	35
Low shade tolerance				
Setaria sphacelata cv. Kazungula	5	7	1	4
Digitaria decumbens cv. Transvale	4	1	47	17

Source: Chen and Bong 1983.

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Growth of Tree Legumes under Coconuts in Bali

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Abstract

An experiment was conducted to study the growth and adaptation of legume species under coconut plantations at Pulukan, Bali. *Desmodium rensonii*, *Calliandra* sp., *Gliricidia sepium* (local), and *Codariocalyx gyroides* were the highest-yielding tree legumes both in leaf and total yield. *C. calothyrsus* and *G. sepium* produced more of their growth as leaf, while *D. rensonii* and *C. gyroides* produced almost the same proportions of leaf and stem.

TREE legumes have been used as a traditional fodder source for ruminants in Bali. Nitis et al. (1980) listed nine tree legume species among 50 species of trees used for ruminant feeding in Bali. Their tall growth habit, deep root system and high leaf-protein content have led to their use as feed supplements and as standing feed for the dry season. In addition, their branches and stems provide fuel wood for cooking (National Academy of Science, 1979; Horne et al., 1989).

Forages under coconuts often consist largely of grasses and only a very small proportion of herbaceous legumes. This may be attributed to the intensive grazing pressure in Balinese plantations. Tree legumes have a clear competitive advantage over herbaceous species and are likely to persist well under current management systems.

Tree legumes are also required as supports and shade for vanilla and pepper. The leaves and branches of these live stakes are lopped and used for ruminant feeding. In the past, leucaena (*Leucaena leucocephala*) has been used for this purpose, but the psyllid insect has seriously damaged leucaena and other psyllid-resistant tree legumes are required.

A selection of tree legumes was therefore evaluated for growth in a coconut plantation to identify suitably adapted species. Some local species were also included for comparison and the results of this evaluation are reported here.

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Materials and Methods

The experiment was conducted under an old coconut stand (100 trees/ha) which was interspersed with young coconut trees at Pulukan, 60 km west of Denpasar, Bali (8°30'S). The light transmission, measured at 1100 hours on a sunny day, was 58% of ambient photosynthetically active radiation (PAR). The soil was a sandy clay loam over a clay loam with a pH of 6.5. The mean annual rainfall in the area is 2070 mm and there is a pronounced, short dry season of three months (monthly rainfall less than 100 mm).

Fourteen introduced tree legume species (seed supplied by the Australian Tropical Forages Genetic Resource Centre, CSIRO, Brisbane) and three local species were included in this experiment (Table 1).

Seeds were inoculated with an appropriate inoculant and seedlings were raised in a nursery before being transplanted into the field in June 1988. The trees were planted as single plants in raised plots at a spacing of 1 × 1 m. The experiment was replicated five times in a completely randomised block design.

The plants were visually rated monthly for vigour, plant survival, disease and insect incidence, flowering and seed production. After an establishment period of three months, trees were harvested every eight weeks for a total of six harvests. At harvests, the main stem of trees was cut at 1 m height and all branches were cut at a distance of 20 cm from the main stem.

The harvested material was weighed fresh, subsampled if over 1 kg, and separated into leaf and stem. Samples were sun-dried for 3–5 days before oven-drying at 70°C for 48 hours.

Results and Discussion

Early growth of the tree legumes was good, disease and pest damage was minimal and there were no symptoms of nutrient deficiencies. Accumulated leaf, stem and total dry weight (over six harvests) and mean leaf percentage are presented in Table 1.

Desmodium rensonii was the highest-yielding tree legume in terms of total dry weight with dry matter yield exceeding 1000 g/tree (Table 1). Other high-yielding tree legumes were *Calliandra* sp., *Gliricidia sepium* (local), and *Codariocalyx gyroides*. *C. calothyrsus* and *G. sepium* produced most of their growth as leaves, while *D. rensonii* and *C. gyroides* produced almost the same proportion of leaves and stems (Table 1). Most other species generally did not perform well at this site under coconuts.

Generally, the species with the highest total dry weight also produced the highest leaf dry weight. The highest total leaf dry weight was produced by *C. calothyrsus* followed by *D. rensonii*, *G. sepium* and *C. gyroides* (Table 1). Of these four species, *D. rensonii* and *C. gyroides* flowered profusely throughout the experiment and produced a large amount of seed when left uncut after the last harvest. *Calliandra* sp. produced some flowers at the end of the dry season while *G. sepium* did not flower at all. However, one of the attractions of *G. sepium* for farmers is the ease with which this species can be propagated vegetatively.

Conclusions

On the basis of the data obtained, four species, viz. *C. calothyrsus*, *C. gyroides*, *D. rensonii* and *G. sepium*, warrant further study as forage species for use in coconut plantations in Bali.

Acknowledgments

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Table 1. Total accumulated dry weight (g/tree) of tree legumes in Bali.

Species	Leaf DW	Stem DW	Total DW	Leaf (%)
Desmodium rensonii CPI 76099	598	564	1162	51
Calliandra sp. CPI 108458	571	243	814	70
Gliricidia sepium (local) Bali	514	279	793	65
Codariocalyx gyroides CPI 49082	415	327	742	56
Desmodium salicifolium CPI 70257	323	229	552	59
Desmodium distortum CPI 28324	297	259	556	53
Flemingia macrophylla CPI 100793	296	122	418	71
Erythriyna sp. (local) Bali	193	95	288	67
Leucaena diversifolia CPI 46568	166	128	294	57
Acacia angustissima	159	71	230	69
Sesbania grandiflora (local) Bali	127	88	215	59
Desmodium discolor CPI 39075	119	112	231	52
Sesbania sesban (local) Bali	75	92	167	45
Leucaena pallida CPI 91309	75	49	124	61
Leucaena diversifolia CPI 46568	59	51	110	53
Leucaena leucocephala cv. Cunningham	38	13	51	74
Pseudarthria hookeri CPI 70286	34	17	51	66

Growth of Tree Legumes under Coconuts in North Sulawesi

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Abstract

Thirteen introduced and local tree legumes were evaluated for growth and yield under coconuts with a light transmission of 70% in the wet tropical environment of North Sulawesi. The introduced accession of *Calliandra* sp. produced by far the highest leaf yields, but *Flemingia macrophylla, Gliricidia sepium, Calliandra calothyrsus* (local), *Desmodium rensonii* and *Codariocalyx gyroides* also showed potential.

In North Sulawesi, leguminous shrubs and trees such as *Gliricidia sepium* and a local variety of *Erythrina* sp. are commonly used as fences and as live stakes under coconuts to provide shade for climbers such as vanilla. These species also provide high quality forage which could be used as a supplement to the low quality naturally occurring grasses. At present there is little information on the adaptation and productivity of the range of tree legume germplasm available for growing under coconuts in North Sulawesi.

This paper reports the results of an evaluation of the growth and yield of a selection of introduced and local tree legume species growing under a coconut plantation.

Materials and Methods

This experiment was conducted at Kayawatu (Lat. 1°30' N) near Manado Airport in North Sulawesi. The total annual rainfall of 2700 mm is relatively evenly distributed except for a period of lower rainfall (100–150 mm per month) from July to September. The soil was a sandy loam with a pH of 6.0. With the exception of phosphorus, the fertility of the soil was high. Transmission of photosynthetically active radiation (PAR) at the site under mature tall coconuts averaged 70% at 10 a.m. on a sunny day.

There were nine introduced (seed supplied by Mr Ron Williams, Australian Tropical Forages Genetic Resource Centre) and four local species included in this trial (Table 1). The introduced species were inoculated with known suitable *Rhizobium* strains and all plants were raised in a nursery before being transplanted into the field in August 1988. The local species were planted vegetatively using 30 cm long stakes. Nine plants of each species were planted into separate plots in two rows of 1 × 1 m.

The plants were rated for plant survival, disease and insect incidence, flowering and seed production, initially monthly and later before each harvest. The first harvest was taken four months after planting and subsequently every two months for a total of nine harvests (December 1988 to June 1990).

The main stem and all branches were cut at a height of 1 m. The cut material was weighed fresh in the field and then separated into leaf, stem and inflorescence. Samples were sun-dried before oven-drying at 70°C.

Results and Discussion

Many of the *Flemingia macrophylla* seedlings did not survive transplanting and only two of the original nine plants survived to the first harvest. The seedlings grew poorly and a disease problem was suspected. The surviving two plants grew well and no further disease symptoms were observed. Similarly, only two of the nine vegetatively propagated *Sesbania grandiflora* plants survived to the first harvest. The yield of these two species is therefore based on only two plants and has to be considered with caution.

Survival of the established plants varied with species. All plants of *Desmodium distortum* were uprooted in a storm shortly after the first harvest and died. *Desmodium discolor* plants started to lose vigour after the third harvest and most plants died within the next two harvests. *Desmodium salicifolium*, a low-growing shrub, grew well up to harvest 6 but plants started to die after this harvest. The only other species which lost plants during the course of the experiment was *Sesbania grandiflora*. The two established plants yielded well up to harvest 6, but subsequently, yield dropped sharply and one of the two plants died after harvest 7.

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No disease symptoms were observed on any of the established plants and insect damage was minimal, except for psyllid damage which was severe on *Leucaena leucocephala* cv. Cunningham and less severe on *Leucaena pallida*.

Some flowering and seed production was observed year-round on most species despite the regular cutting. Highest seed yields were observed on *Desmodium salicifolium*, *Flemingia macrophylla* and *Codariocalyx gyroides*. Species which did not flower throughout the experimental period included *Leucaena leucocephala*, *Leucaena pallida*, *Sesbania grandiflora*, *Gliricidia sepium* and *Erythrina* sp.

The total dry weight and leaf proportion over nine harvests are presented in Table 1. *Calliandra* sp. CPI 108458 gave the highest total yield (leaf + stem) of more than 3300 g/tree. Other high yielding species which produced more than 2000 g were *F. macrophylla* and *Desmodium rensonii*. *Calliandra* sp. (local), *Gliricidia sepium* (local) and *Codariocalyx gyroides* were the next highest-yielding species. The highest leaf dry weight was produced by *Calliandra* sp. and *F. macrophylla*, followed by *G. sepium* (local) and *Calliandra* sp. (local). Among the high-yielding species, *D. rensonii* and *C. gyroides* had a high proportion of stem.

Leaf yield of the five highest-yielding species over nine harvests is presented in Figure 1. Leaf yield of *Calliandra* sp. was the highest among all species throughout the experiment, but *F. macrophylla* also produced high leaf yields in the later harvests. *Desmodium rensonii* and *C. gyroides* produced high leaf yields initially but these were lower in later harvests. These two species appear to be shorter-lived than the other high-yielding trees but, because of their high initial growth rate, these species may be suitable in ley farming systems or may be used to overcome short-term feed limitations. While producing a high leaf yield initially, yield of *G. sepium* declined in later harvests. It is interesting to note the difference in productivity between the local and introduced *Calliandra* sp. accessions. It appears that there is scope to select higher-yielding accessions within this species. The introduced accession of *Calliandra* sp. in this trial produced some root suckers which may prove unacceptable to farmers.

In the drier environment of South Sulawesi, Ella et al. (1989) found little difference between leaf yield of *C. calothyrsus*, *L. leucocephala* and *G. sepium*, while the yield of *Calliandra* sp. was clearly superior in North Sulawesi. Presumably, the yield of *L. leucocephala* was severely limited by psyllid damage in our experiment while the experiment reported by Ella et al. (1989) was conducted prior to the arrival of psyllids.

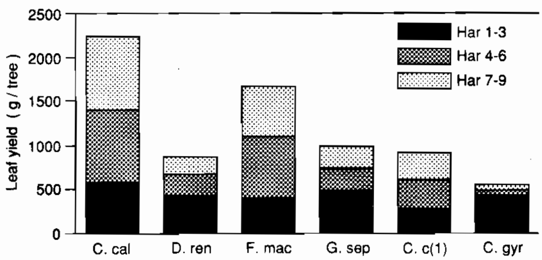

Fig. 1. Leaf yield (g DW/tree) of the highest-yielding tree species grown under coconuts at Manado, North Sulawesi.

Explanation for abbreviations :

C. cal = *Calliandra* sp. CPI 108458;
D. ren = *Desmodium rensonii* CPI 76099;
F. mac = *Flemingia macrophylla* CPI 100793;
G. sep = *Gliricidia sepium* (local);
C. c(l) = *Calliandra calothyrsus* (local);
C. gyr = *Codariocalyx gyroides* CPI 49082.

Table 1. Total accumulated dry weight (g/tree) of tree legumes in Manado.

Species	Leaf DW (g/tree)	Stem DW (g/tree)	Inflorescence DW (g/tree)	Total DW (g/tree)	Leaf (%)
Calliandra sp. CPI 108458	2231	1120	1	3352	67
Flemingia macrophylla CPI 100793	1654	794	60	2508	66
Desmodium rensonii CPI 76099	860	1234	21	2115	41
Calliandra calothyrsus (Local)	922	583	2	1507	61
Gliricidia sepium (Local)	980	496	0	1476	66
Codariocalyx gyroides CPI 49082	557	534	36	1127	49
Erythrina sp. (green leafed type) (Local)	414	380	0	794	52
Leucaena pallida CPI 91309	487	421	0	908	54
Leucaena leucocephala cv. Cunningham	486	373	0	859	57
Desmodium distortum CPI 28324	155	428	2	585	27
Desmodium salicifolium CPI 70257	300	231	57	588	51
Sesbania grandiflora (Local)	266	146	0	412	65
Desmodium discolor CPI 39075	115	122	3	240	48

Conclusion

Of the 13 tree legume species evaluated, *Calliandra* sp. CPI 108458 produced by far the highest leaf yields. Other potentially useful species were *F. macrophylla*, *C. calothyrsus* (local), *G. sepium* (local), *D. rensonii* and *C. gyroides*.

Acknowledgments

This work was carried out as part of an ACIAR-funded collaborative research program between Sam Ratulangi University, North Sulawesi, Indonesia and The University of Queensland, Australia, entitled 'Improvement of forage productivity in plantation crops'. We are grateful for the funding and support received from these organisations. We also thank the Australian Tropical Forages Genetic Resource Centre for help in the selection of tree legume species and the supply of seed and inoculum.

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Shade Tolerance of Some Tree Legumes

A. Benjamin*, H.M. Shelton* and R.C. Gutteridge*

Abstract

The shade tolerance of some commonly used tree legume species was compared in a glasshouse experiment at the University of Queensland in 1988. The treatments were 100, 70, 50, 30, and 20% of photosynthetically active radiation effected using shade cloth in a glasshouse. Shade tolerance was assessed by comparing yield at low light levels with that obtained at high light. Using this criteria, shade tolerance was assessed in the descending order *Gliricidia sepium* > *Calliandra calothyrsus* > *Leucaena leucocephala* > *Sesbania grandiflora* > *Acacia villosa* > *Albizia chinensis*.

PRODUCTIVE high quality forage species, adapted to shade environments, are required to improve the animal production of ruminants integrated into plantations crops. Most species that have been used for this purpose are herbaceous (Gutteridge and Whiteman 1978, Shelton et al. 1987). Shade-adapted legumes, in particular, are sought for inclusion in pastures because of their superior quality and their ability to contribute biologically fixed nitrogen to the plantation crop.

Several studies have reported the shade tolerance of herbaceous legume genotypes which may be suitable for use in plantation environments (Eriksen and Whitney 1982, Wong et al. 1985). However, very little attention has been directed to understanding the shade response of tree legumes, which may also be planted under perennial tree crops to provide additional shade or fodder for ruminants. One exception is the study of Egara and Jones (1977), who showed *Leucaena leucocephala* to have limited shade tolerance.

This study was initiated to provide information on the comparative response to shade of some commonly used fodder tree legumes.

Materials and Methods

A glasshouse experiment was conducted between April and August 1988 at the University of Queensland to compare the response of six fodder tree legumes to a range of light intensities. The experimental design was a complete randomised block in a split-plot arrangement with two replications.

The main plots were 100, 70, 50, 30 and 20% of incident light transmission inside the glasshouse. Shade treatments were effected using a range of commercial shade cloths supported on plastic frames erected on benches. The glasshouse reduced incident light of all treatments by approximately 30%.

The six tree legumes evaluated were *Acacia villosa, Albizia chinensis, Calliandra calothyrsus, Gliricidia sepium, Leucaena leucocephala* and *Sesbania grandiflora.*

Two plants of each species were established in pots containing 4 kg of a red krasnozem soil obtained from the University of Queensland farm at Redland Bay. Pots were fertilised at fortnightly intervals to provide a total fertilizer application in kg/ha of 185 N, 61 P, 184 K, 125 Ca, 0.53 Cu, 0.18 Zn, 0.53 B, 0.35 Mn, 0.02 Mo and 0.05 Fe. Water was applied daily to pots to field capacity and fungicide was applied to inhibit fungal damage to young seedlings.

Plants were first grown for 25 days without shade cloth before the shading treatments commenced. These were continued for 70 days when plants were harvested, separated into leaf and edible stem (< 6 mm in diameter), stem and root fractions, and oven-dried at 60°C.

Results and Discussion

The mean dry matter yield response of the species showed a decline as the light level declined (Fig. 1). The mean yields were 42, 39, 32, 31 and 28 g/pot for the 100, 70, 50, 30 and 20% PAR treatments respectively. However, the extent of these effects varied among the species. Yields of *A. villosa, S. grandiflora* and *A. chinensis* were significantly reduced by shade; however, yield reductions in *L. leucocephala, C. calothyrsus* and *G. sepium* did not reach significance.

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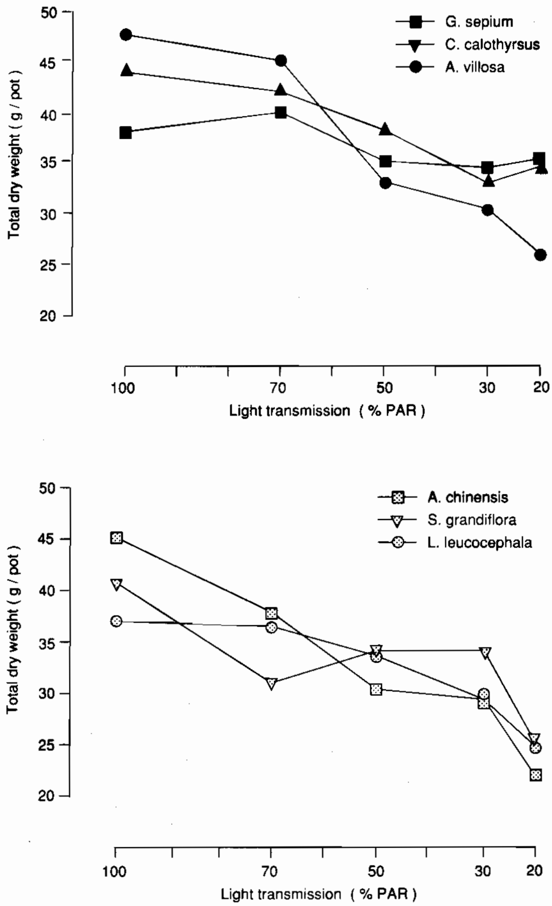

Fig. 1. Yield (DM g/pot) of tree legumes grown at five light levels.

When yield performance under all shading treatments was expressed as a percentage of yield at 100% light transmission, the relative order of shade tolerance was *G. sepium* (94%), *C. calothyrsus* (85%), *L. leucocephala* (84%), *S. grandiflora* (76%), *A. villosa* (70%) and *A. chinensis* (66%). When yield under very low light was examined, the relative yield performance of the species compared to 100% light transmission was *G. sepium* (92%), *C. calothyrsus* (78%), *L. leucocephala* (68%), *S. grandiflora* (62%), *A. villosa* (54%), and *A. chinensis* (48%).

The mean percentage of top growth ranged from 60–70% for all species with a trend towards less root growth at lower light levels (data not presented). Only in *A. villosa* was there a substantial increase in top yield relative to root yield at lower light levels.

These findings are in general agreement with those of Egara and Jones (1977), who demonstrated the moderate shade tolerance of leucaena, and with Egara and Jones (1977) and Wong et al. (1985) who showed increased root to shoot ratios under shade.

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Improvement of Nitrogen Nutrition and Grass Growth under Shading

J.R. Wilson* and D.W.M. Wild**

Abstract

In most tropical grasses the decrease in yield under shade is approximately proportional to the amount of shading, provided that water and nutrients are not limiting. However, in special circumstances, yield of these same 'sun species' can show the opposite response and increase under shaded conditions.

Published data and the current experiments showed this response occurs under conditions where growth in full sun is restricted by nitrogen deficiency. Shade increases the availability of soil nitrogen and this stimulates plant growth. The effect clearly resides in the soil and is not shown by plants grown in solution culture. Currently work is underway to measure the rate of soil nitrogen mineralisation under shade and full sun conditions, and to relate changes in this rate to soil and litter environmental conditions.

MOST tropical pasture grasses, except obligate shade species, when well supplied with nutrients and water will have lower yield in shade than in full sunlight. The decrease in yield under shade will be approximately proportional to the degree of shade experienced. However, in special circumstances, yield of these same 'sun species' can show the opposite response and increase under shaded conditions. Many observers of the South African savannas have reported especially good growth of grass under the canopy of leguminous trees compared with outside the canopy in full sun. Often though, this has been accompanied by a shift in plant species. Lowry et al. (1988) in Townsville, Australia recorded a 250% higher yield of guinea grass (*Panicum maximum*) under the shade of the canopy of *Albizia lebbek* trees compared with that of the same species in the full sun outside the canopy. Wilson et al. (1990) showed that such responses are not confined to grasses in the understorey of leguminous trees. They reported a 35% greater growth of bahia grass (*Paspalum notatum*) under approximately 55% light transmission within a plantation of *Eucalyptus grandis* trees than obtained from the same grass in full sun outside the plantation. The increase in dry matter yield was accompanied by an even larger increase (67%) in nitrogen yield of the herbage.

These beneficial tree canopy effects are commonly believed to be due to leaf drop, better nutrient cycling, higher soil organic matter and improved soil physical structure (Young 1989), and to nitrogen fixation in the case of leguminous trees.

However, it is now apparent that a large part of the increased growth of grass under tree canopies can be directly associated with the shade provided because similar yield responses have been demonstrated under artificial shade cloth. Wong and Wilson (1980) found a 27% increase in shoot yield and a 76% increase in nitrogen yield of 8-week cut Green panic (*Panicum maximum* var. *trichoglume*) grown under 40% light transmission compared to full sun. Wilson et al. (1986) with a run-down Green panic pasture showed a similar increase in dry weight and nitrogen yield under 50% shade cloth on a heavy clay soil at the Narayen Research Station in south-east Queensland. In contrast, the legume siratro (*Macroptilium atropurpureum*) did not show a positive growth response to the same shade conditions (Wong and Wilson 1980).

These responses all seem to occur when soil nitrogen is limiting growth under full sun. This interaction with nitrogen supply was shown by Eriksen and Whitney (1981), who grew grasses under high or nil nitrogen supply. In the nil nitrogen treatment, yield of whole plant (shoot + root) of guinea grass and cori grass (*Brachiaria miliiformis*) under dense shade giving 27% light transmission was respectively 11 and 62% higher than under full sun, and that of mealani grass (*Digitaria decumbens*) under 45% light transmission was 26% higher. Under high nitrogen supply, the normal shade response was obtained and yield decreases of 60, 31, and 34% were recorded for the three species, respectively.

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These studies have led to the hypothesis (Wilson 1990) that shade (tree or artificial) increases the availability of soil nitrogen and that this leads to better growth of grass under shade than in full sun when nitrogen is a limiting factor. Preliminary results of current experiments reported here support this hypothesis.

Material and Methods

Three experiments are briefly described, two conducted in the field and one using a solution culture technique.

Experiment 1

The site is at the CSIRO Narayen Research Station in central Queensland on two soil types, a heavy clay soil and a light sandy duplex soil. The station is in a semi-arid, subtropical environment, with average annual rainfall of 719 mm. Three pasture types were selected for study on each soil, viz. Green panic, buffel (*Cenchrus ciliaris*) and rhodes grass (*Chloris gayana*) on the clay soil, and Green panic, buffel and spear grass (*Heteropogon contortus*) on the sandy soil. All pastures had been established for many years, had never received nitrogen fertilizer, and growth in full sun was limited by nitrogen deficiency. Matched areas of pasture were selected and artificial shades (shade cloth) giving 50% light transmission erected over one area, the other retained as a full sun control. The shades were 7 × 5.2 m in size and were mounted 1.8 m above the pasture to allow good air movement over the sward. All pastures were grown under natural rainfall, except that in the Green panic pastures additional plots were set up, and on these plots drip irrigation tubes were spaced 0.5 m apart across the plot to give an irrigated treatment. These plots were watered whenever soil water potentials fell below about -0.1 MPa. There were three replicates of each treatment. The treatments commenced in October 1988.

Yield harvests of total tops cut at ground level were taken from predetermined 1 m × 0.5 m quadrats on 9 January, 6 March, 22 May and 28 November 1989, and on 22 January 1990. At each harvest, a sample of recent fully-expanded leaves was taken for nitrogen analysis.

Also, soil cores to 10 cm depth were taken for soil water content, analysis of nitrate and ammonium concentrations, and root extraction. Instrumentation on the various treatments recorded two-hourly mean temperatures for the air at canopy height, litter, and soil at 2 and 5 cm depths. Gypsum blocks were used to obtain soil water contents at 5, 10 and 20 cm depths on a weekly basis.

Experiment 2

This experiment was conducted in Brisbane during the early summer of 1989–90. Solution culture was used to remove the soil component from the shade response. Green panic plants were grown outdoors in tanks (2.1 × 0.85 × 0.3 m deep) holding 480 L of base nutrient solution (without N) under continued recirculation by pumps. A computer-programmed daily addition of nutrients was made to match growth requirements. Two nitrogen treatments were established: one provided a level allowing maximum growth rate (high N), the other at one-quarter of this rate to give a nitrogen–limited situation (low N). Seedlings were raised in sand in trays and transferred to the solution culture system 21 days after germination (5th leaf stage). A shade treatment was imposed the next day by covering one half of each tank with shade cloth (50% light transmission) both above and around the sides of the plants. Four tanks were used to give two replicates of the low and high N treatments.

Harvests were taken every ten days from the start of the shade treatment. Six to ten plants were sampled for each replicate for each treatment, separated into tops and roots and dried overnight at 70°C. Only data from the last harvest at 40 days of treatment are presented. Nitrogen analyses of material have not yet been done.

Experiment 3

This site is at the CSIRO Samford Research Station near Brisbane on a red–yellow podzolic soil. The environment is subtropical with an average annual rainfall of 1117 mm. The pasture is an old established area of nearly 100% pure bahia grass, one half the area is under the shade of a seven-year-old plantation of E. grandis trees at a 6.5 × 6.5 m spacing. This provides an average level of about 55% light transmission. The remaining area is in full sun and on this area 16 plots were located. In August 1989, eight of these plots were allocated at random to an artificial shade treatment and were covered with shadecloth (50% light transmission) 8.2 × 6.2 m at 1.6 m height to cover a sample area of 5 × 3 m. This gave eight replicates of full sun and shade plots. Eight plot areas of 3 × 3 m were also located in the interrows within the plantation of trees.

Temperature sensors were placed on the soil surface under the litter layer, and in the soil at depths of 2.5, 7.5 and 15 cm. Two-hourly mean temperatures were logged continually. Gypsum blocks were placed in the soil at 2.5, 5, 10, 20 and 40 cm to monitor changes in soil water. Effects of treatments on soil nitrogen mineralisation rate were measured periodically using an in situ soil core technique, followed by removal of the core and analysis of soil for changes in nitrate and ammonia concentrations. Harvests of 1 × 0.5 m quadrats were made after various periods of regrowth to give dry weight yield of tops (above 5 cm) and stubble (0–5 cm). The only data presented here are for the soil surface (under the litter) and 15 cm soil temperatures under trees, artificial shade and full sun.

Results and Discussion

Experiment 1

The cumulative herbage yields over the five harvests in the Narayen field experiment (Table 1) show a positive response in grass growth to shade ranging from 25 to 48% for most of the pasture treatments. Only buffel grass on the clay soil showed no effect of shade. The response of speargrass was small and largely reflected an increase in weed growth rather than that of the speargrass itself. In the other pastures, it was the designated grass that showed a strong response, although weed growth was also promoted, particularly in the spring harvest. The irrigated green panic showed a greater shade response than the natural rainfall treatment on the clay soil but not on the sandy soil.

Not only was yield increased under shade but leaf nitrogen percentage was also increased at every harvest. Data for the 6 March harvest are given in Table 1 as an example. At this same harvest, soil nitrate concentrations were also higher in the shade than the sun treatment (Table 1). This effect was not observed at each harvest, and no consistent differences in ammonium-N concentrations were recorded between the treatments.

This experiment shows that the response can occur equally well on different soil types. The response is most strong in green panic which is known to have a moderate degree of shade tolerance, and less strong in buffel and speargrass, species considered more suited to open grassland areas. One of the suggested possible benefits of shade leading to better growth is that soil water content is maintained at a higher level for longer than in full sun. This would certainly appear to be true, at least near the soil surface (Fig. 1). However, reducing plant water stress would not appear to be an important factor here because the natural rainfall treatment did not show any greater shade response than the irrigated treatment, even though periods of water stress were common during the experiment. The major response appears to be due to an increase in available soil nitrogen.

The benefits of the increased soil nitrogen and hence increased leaf N% outweigh the detrimental effects of decreased light input under shade. This is illustrated diagramatically in Figure 2, with leaf photosynthesis light response curves based on data presented in Wilson (1975). Because of the very flat response curve when nitrogen is deficient (low N), a decrease in light to 50% results in only a small decrease in photosynthesis. If, however, this shading to 50% light transmission results in an increase in leaf N% so that the leaf response shifts to the medium N curve, then even with only 50% light the photosynthetic rate is higher than that of the N-deficient leaves in full sun (100% light on low N curve). On the other hand, when N supply is maximal the light response curve is very steep (high N) and shading causes an almost linear decrease in photosynthetic rate.

Experiment 2

The solution culture experiment gave quite opposite results to the field experiment. Shoot and root dry weight yields were reduced 55–61% by the 50% shade

Table 1. Experiment 1: effect of shade on dry weight yield of tops (t/ha), leaf nitrogen concentration (%) and soil nitrate-N concentration (ppm of oven dry soil).

	Brigalow clay soil				Spear grass sandy soil			
Pasture Type	Green panic I[a]	Green panic NI[a]	Buffel	Rhodes	Green panic I[a]	Green panic NI[a]	Buffel	Spear grass
Top DW yield[b]								
Shade	23.41	15.65	15.76	15.09	13.41	9.73	13.58	7.51
Sun	16.31	12.39	16.59	11.40	9.07	6.59	10.81	6.59
Relative effect of shade	+44%	+26%	-5%	+32%	+48%	+48%	+26%	+14%[c]
Leaf nitrogen[d]								
Shade	2.81	2.89	2.08	1.53	2.64	2.64	1.79	1.38
Sun	2.21	2.23	1.64	1.34	2.39	2.58	1.49	1.49
Soil nitrate								
Shade	8.9	7.8	4.0	9.6	3.2	2.1	2.6	1.2
Sun	4.3	4.4	3.0	7.6	2.6	1.3	1.6	1.3

a. I (irrigated); NI (non-irrigated)
b. Based on cumulative yield totals over five harvests
c. Response mainly due to increased weed growth
d. Nitrogen concentration in the youngest fully expanded leaf of each grass species at harvest on 22 May 1989.

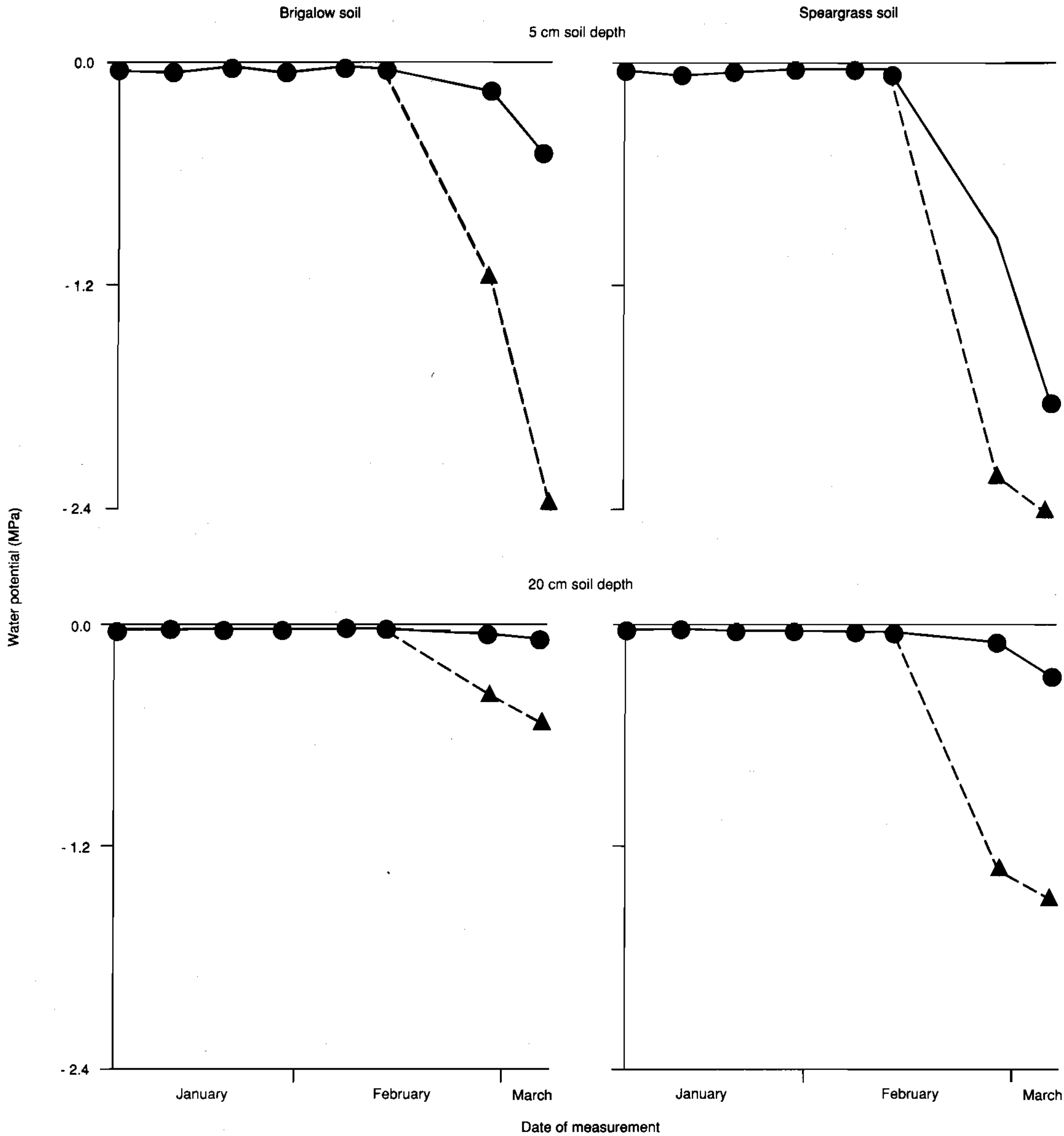

Fig. 1. Experiment 1: change in soil water potential at 5 and 20 cm soil depths for the non-irrigated green panic plots on both soil types for the six-week period leading up to the harvest on 6 March 1989. Shade (—-), sun (....).

treatment (Table 2). There was virtually no change in shoot–root ratio.

Thus, irrespective of the plant nitrogen status, in the absence of soil there is no positive response in grass growth to shade. Growth was reduced in proportion to the reduction in light. This experiment indicates quite clearly that the positive responses in grass growth to shade are due to changes occurring in the soil. These are believed to be associated with an increase in soil mineralisation rate.

Experiment 3

This experiment at Samford was primarily designed to test the hypothesis that a positive shade response is due to increased soil N mineralisation, and to gain some understanding of what is causing this change in

Table 2. Experiment 2: effect of 50% shade on growth of green panic in solution culture at high and low N levels after 40 days treatment.

Plant attribute	High N		Low N		Relative effect of shade	
	Sun	Shade	Sun	Shade	High N	Low N
Shoot DW (g)	78.1	33.6	42.2	19.1	-57%	-55%
Root DW (g)	6.9	2.7	7.4	3.1	-61%	-58%
Shoot–root ratio	11.4	12.2	6.1	6.3	+7%	n.s.

n.s.: no significant effect; all other effects significant at P<0.05.

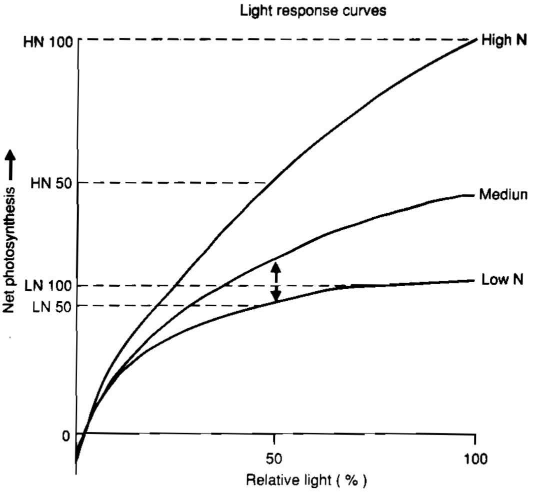

Fig. 2. Diagrammatic photosynthesis light response curves for leaves at low, medium and high nitrogen concentrations, illustrating the effects of a change in shade or nitrogen level.

mineralisation. Possibly shade ameliorates the environmental conditions at the soil–litter interface allowing greater microbial activity and, through this, faster N mineralisation. The soil water data from Narayen (Fig. 1) supports the idea that shade reduces the rate of soil water decline in dry periods. The data from this experiment for the water content at the soil surface will be compared in due course with rates of soil mineralisation over dry and wet periods. The other factor which may have some influence is temperature of the litter and soil surface. Under shade these temperatures may stay at a moderate level during the day but in the sun, soil surface temperatures may go as high as 50°C (Fig. 3). Answers to these questions should be obtained over the next 12 months. Greater numbers and activity of soil fauna such as earthworms under shade is another possibility that could be important in relation to faster litter breakdown and turnover of nitrogen.

Conclusions

Published data and the current experiments clearly show that under some circumstances grass growth under shade can be significantly increased. This response occurs under conditions where growth in full sun is restricted by nitrogen deficiency. Shade increases the availability of soil nitrogen and this stimulates plant growth. The effect clearly resides in the soil and is not shown by plants grown in solution culture. Currently work is under way to measure the rate of soil nitrogen mineralisation under shade and full sun conditions, and to relate changes in this rate to soil and litter environmental conditions.

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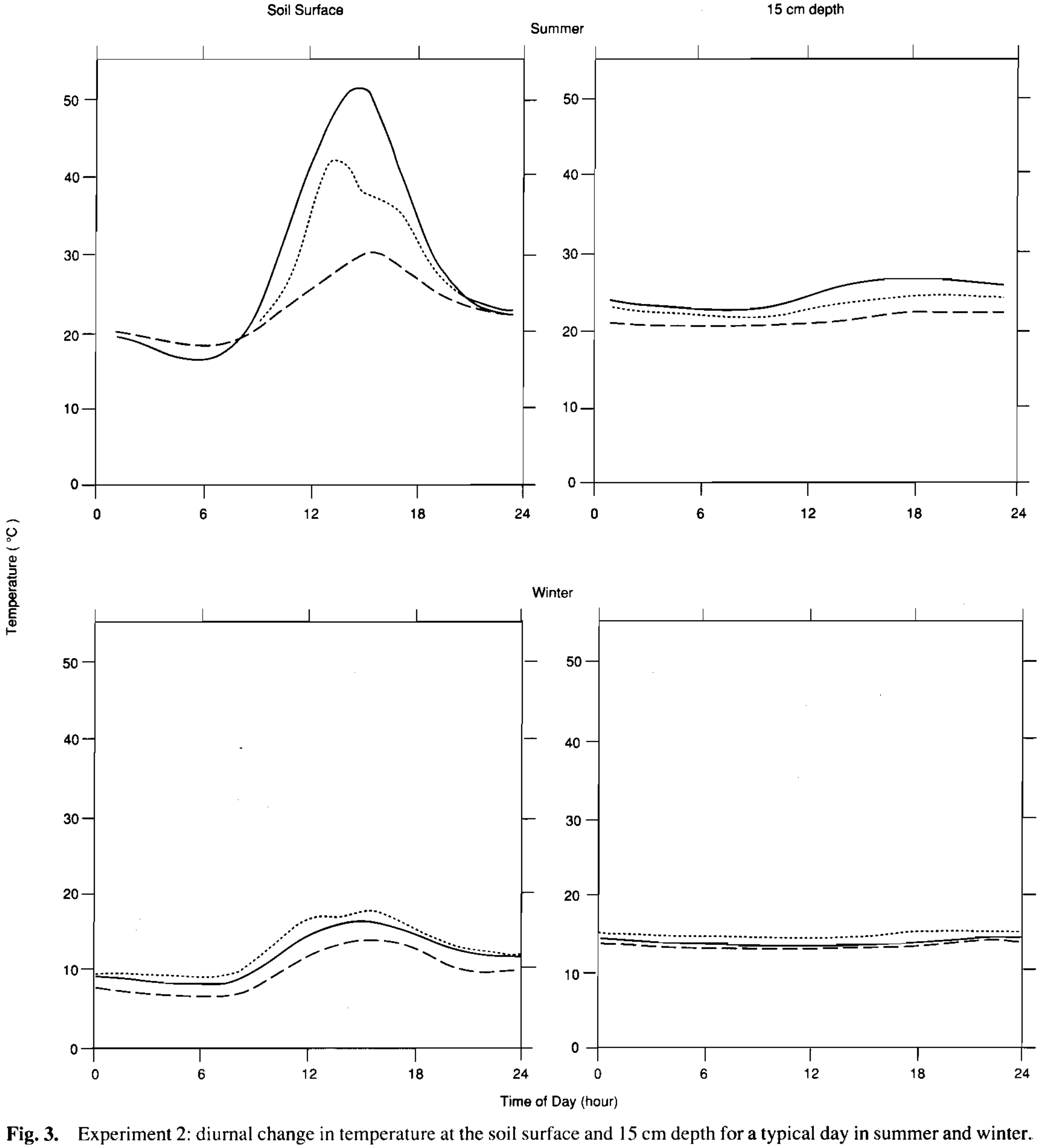

Fig. 3. Experiment 2: diurnal change in temperature at the soil surface and 15 cm depth for a typical day in summer and winter. Artificial shade (- - -); tree shade (....) and sun (——)..

The Effect of Shade on Forage Quality

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Abstract

The effects of shading on the nutritive value and chemical composition of five tropical grasses was investigated in two experiments. The grasses used were setaria (*Setaria sphacelata* cv. Kazungula), green panic (*Panicum maximum* var. *trichoglume* cv. Petrie), guinea grass (*Panicum maximum* cv. Riversdale), signal grass (*Brachiaria decumbens* cv. Basilisk) and bahia grass (*Paspalum notatum*). In the first experiment, grass grown in full sun or under shade (50% light transmission) was cut, dried and fed to sheep in pens. Shading decreased the yield of herbage and increased the N content of all grasses except bahia grass. Bahia grass had an increased yield as well as an increased N content when grown under shade. There were no significant effects of shading on cell wall composition, voluntary feed intake (VFI) or in vivo dry matter digestibilities (DMD) of the grasses. The DMDs of setaria and signal grass were significantly higher (66.8 and 64.2% respectively) than that of other grasses (range 55.9 – 59.5%). Sheep consuming herbage grown under shade had higher ammonia and propionic acid, but lower acetic acid, concentrations in the rumen. They also had higher N-balances than did sheep fed sun-grown pastures. These differences were greatest for setaria and signal grass.

In the second experiment, the same grasses were grown at light levels of 100, 68, 50 and 30% of full sunlight, and yields and chemical composition were measured for four successive, 6–8–weekly regrowths. Decreasing light level decreased herbage yields at the initial harvests but increased yield at the final harvest. Shade decreased herbage dry matter content and increased protein content but had no consistent effect on either the proportion of leaf or the chemical composition of the plant cell walls. The effect of low light on DMD was variable between species and harvests, with a tendency toward a small decrease in DMD at the lowest light level. It was concluded that, for the grasses studied, shading (50% light transmission) had little effect on their cell wall composition or on their VFI or DMD when fed to sheep. However, the increased N–content of shaded plants may improve nutritive value if the N–content of sun-grown plants is low (< 10 g N/kg DM).

FORAGE quality is directly related to the extent to which the plant provides nutrients for grazing animals. Quality is often measured as the product of voluntary feed consumption and the digestibility of nutrients consumed. The chemical composition of the plant may also be used as a guide to forage quality. The effects of shade on pasture growth were recently reviewed by Wilson (1988), and for most tropical grass species yield decreases with decreasing light (Ludlow 1978). However, the 'shade tolerant' grasses often show little yield depression or even increased yield under moderate light levels (Wong et al. 1985, Samarakoon et al. 1990a). It is these species which may be useful forage plants in plantation crops.

The effects of shading on the nutritive value of forage are less clear. Shading usually reduces the total non-structural carbohydrate of grasses (Hight et al. 1968; Wilson and Wong 1982; Samarakoon 1987) but has variable (positive and negative) effects on cell wall content and composition, lignin and in vitro digestibility of plant dry matter (Wilson 1988).

There have been only two studies where shaded and unshaded forages were evaluated as a feed for animals (sheep). Hight et al. (1968) compared shaded ryegrass (2–3 days shading at 22% light transmission) with unshaded ryegrass and found that this shading decreased soluble carbohydrate content by 3.7% units, dried forage digestibility by 0.6–3.6% units, and voluntary feed intake by 12–15%. However, since the shading period was very short, the results may have little relevance to the interpretation of the longer-term effects of shading on tropical pasture grasses grown under plantation crops. The other study (Samarakoon et al. 1990b) studied the effects of much longer periods of shade (50% light transmission) on the nutritive value of buffalo grass (*Stenotaphrum secundatum*) and kikuyu grass (*Pennisetum clandestinum*) for sheep. There were no significant effects of shading on digestibility (in vivo and in

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vitro) or cell wall composition but there was a marked depression (28–33%) in feed intake of sheep given shaded kikuyu grass. These workers have suggested that the decreased intake was associated with the increased stem content of shaded kikuyu grass, but this effect was found in only one of the harvests fed. An alternative explanation for this depression in intake may be decreased palatability of the feed.

The following experiments were conducted to investigate further the effects of shading on the voluntary feed intake and digestibility of tropical grasses by sheep. The relationship between changes in plant composition during shading and nutritive value were of particular interest, since this information may permit the prediction of shade effects on nutritive value.

Materials and Methods

Two experiments are described in this paper. The first investigated the effects of a single level of shading on the voluntary intake and digestibility of five tropical grasses when fed to sheep, and the second studied the effect of decreasing light levels on the chemical composition and in vitro digestibility of seven tropical grasses.

Experiment 1.

Thirty weaner sheep (Border Leicester × Merino) were held in metabolism cages during the 28-day feeding trial. The following grasses were grown in replicated plots (5) either in full sunlight or under shadecloth (50% light transmission). The grasses were setaria (*Setaria sphacelata* cv. Kazungula), green panic (*Panicum maximum* var. trichoglume cv. Petrie), guinea grass (*Panicum maximum* cv. Riversdale) and signal grass (*Brachiaria decumbens* cv. Basilisk). The grasses were fertilised with 125, 25 and 50 kg/ha N,P,K to maintain a good growth rate. All plots were slashed to 10 cm and then harvested for the feeding experiment after 6 weeks regrowth. An established stand of bahia grass (*Paspalum notatum*) growing under the shade (approximately 50% light transmission) of *Eucalyptus grandis* trees at Samford Research Station (CSIRO) and an adjacent open area with the grass growing in full sun were slashed in March, and the herbage from both plots harvested after a period of after–6–weeks regrowth. All harvested material was weighed, dried, chaffed and stored for subsequent feeding.

The design of the feeding trial was therefore five grass species by two light treatments (sun and shade) by three sheep per treatment. Measurement of voluntary feed consumption, feed digestibility, nutrient balances and sampling of rumen fluid took place in the last week of the 4-week feeding period. Feed, refusals and faeces were analysed for dry matter (DM), ash, neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin. Cellulose (ADF-lignin) and hemicellulose (NDF-ADF) contents were calculated from the organic matter content of the detergent fibre fractions. Total N and P contents were determined on these fractions and in urine. In vitro digestibility was determined by incubation with cellulase and pepsin (McLeod and Minson 1978). Rumen fluid was collected with a stomach tube before the morning feed and was analysed for ammonia, volatile fatty acid (VFA) concentrations and proportions. Analysis of variance was used to determine the significance of differences between treatments.

Experiment 2.

This experiment was designed to investigate the effects of decreasing light level (100, 68, 50 and 30% light transmission) on the growth and chemical composition of seven tropical grass species. The following species were sown in replicated plots at Redland Bay Research Station in southeast Queensland: setaria (*Setaria sphacelata* cv. Kazangula), green panic (*Panicum maximum* var. trichoglume cv. Petrie), guinea grass (*Panicum maximum* cv. Riversdale), signal grass (*Brachiaria decumbens* cv. Basilisk), buffalo grass (*Stenotaphrum secundatum*) and a mixture of mat grass (*Axonopus compressus*) and sour grass (*Paspalum conjugatum*). Each plot was successively harvested at 6–8-weekly intervals after an initial clearing cut after establishment. The plots were fertilized with 25, 64 and 50 kg/ha N,P,K at establishment. Total dry matter yields and proportions of leaf, stem and dead material were determined at each sampling. The material taken from harvests 2 and 4 was chemically analysed for the components described in Experiment 1. Total non-structural soluble carbohydrates were analysed by the technique described by Weier et al. (1977). Results were statistically analysed by analysis of variance.

Results and Discussion

Experiment 1

Table 1 shows mean values for yield and chemical composition of the five grasses grown under shade for the sheep feeding trial. Shading decreased the yields of setaria (45%), green panic (25%), guinea grass (40%) and signal grass (61%). Shading increased leaf and decreased stem fractions in setaria, but no changes were seen in the proportions of leaf in the other species. The yield of bahia grass (*Paspalum notatum*) was increased under shading but this effect cannot be compared directly with the other grasses because of the different environment in which it was grown. Wilson et al. (1990) have previously reported this response of bahia grass to shade.

Table 1. The effects of shade (50% light transmission) on yield and chemical composition of five tropical grass species harvested after six weeks regrowth.

Component		Setaria	Bahia grass	Green panic	Guinea grass	Signal grass	Mean
DM yield (kg/ha)	Sun	4568	2542	3951	4321	7284	4533
	Shade	2519*	3431*	2963*	2963*	2840*	2943*
Leaf(%)	Sun	35	97	54	43	34	52
	Shade	53*	99	57	42	40	58
Stem(%)	Sun	58	0	43	40	54	40
	Shade	42*	0	40	43	47	38
Dead (%)	Sun	4	3	0	17	6	6
	Shade	2	1	0	15	4	4
Inflorescence(%)	Sun	3	0	3	0	6	3
	Shade	3	0	3	0	9	4
NDF (g/kg DM)	Sun	781	778	775	770	784	778
	Shade	742*	777	757	774	778	766
ADF (g/kg DM)	Sun	463	453	502	484	473	475
	Shade	467	435	537*	502	437*	476
Lignin (g/kg DM)	Sun	96	77	93	79	82	85
	Shade	103	63	117	82	76	88
Nitrogen (g/kg DM)	Sun	14.2	11.5	15.7	14.0	10.1	13.1
	Shade	21.2*	10.8	16.9	17.5*	20.4*	17.4*
Phosphorus (g/kg DM)	Sun	1.72	1.54	1.82	1.57	1.48	1.63
	Shade	1.76	1.67	1.78	1.63	2.08	1.78

* Significant difference ($P < 0.05$) between sun and shade values.

The effects of shading on the cell wall content (NDF), ADF (cellulose + lignin), lignin or P content of the grasses sampled were generally small and inconsistent between species, with few differences reaching statistical significance.

There was a significant increase in the N content of setaria, guinea grass and signal grass under shade. It may be calculated that while DM yield was decreased by 25 to 61%, N yield was only decreased by 14 to 21%. The yield of N from the tops of shaded bahia grass was greater than that from sun-grown bahia plants. These aspects of the N economy in shaded plants have been discussed elsewhere (Wilson et al. 1990).

It is usually found that the soluble carbohydrates of plants decrease under shading, and this decrease in cell contents leads to an apparent increase in the cell wall fraction (NDF) of the dry matter cell. Similarly, where the protein content increases, this may also result in an apparent decrease in cell wall fraction. Since these soluble fractions are fully digested, the changes in plant digestibility are predictable.

Cell walls are the major fraction available for digestion and it is important to determine whether shade affects their composition (and hence herbage digestibility). Table 2 shows values for the cellulose, hemicellulose and lignin contents of the cell wall fraction of shaded and unshaded plants in this study. The ratios of hemicellulose to cellulose and lignin to cellulose (lignin proportion of ADF) tend to be constant for a species and may be used as an independent measure of shade effects on the composition of the cell wall. While the species differences are clearly shown in this table, the differences between sun and shade treatments in these values and in in vitro digestibility were small, inconsistent and statistically not significant.

Table 3 gives mean values from the feeding trial conducted with sheep. There was no consistent effect of shade on voluntary feed intake or on the digestibility of any of the components measured. As with feed chemical composition and dry matter, there were significant differences between species. The P content of these feeds was adequate as indicated by the positive balance of all sheep. However, sheep given feeds grown under shade (particularly setaria and signal grass) had higher N-balances than those given sun-grown feeds. It is relevant to note that it was these feeds which had the greatest increase in N concentration under shade. The N requirement of the ruminant needs to be satisfied in two ways: firstly, there is need for sufficient soluble plant N to maintain ammonia levels in the rumen sufficient for the effective action of the microbial population (40 – 60 mg N/l rumen fluid). Secondly, it is desirable that some plant protein pass to the small intestine for direct absorption (undegraded protein). Although liveweight changes were not measured in this study, it was expected that the increased N balance would be accompanied by higher liveweight gains.

Table 2. Effects of shade on the chemical composition of plant cell walls and in vitro digestibility of five tropical grass species.

Component		Setaria	Bahia grass	Green panic	Guinea grass	Signal grass	Mean
Cellulose (g/kg)	Sun	314	349	376	381	367	357
	Shade	243	352	381	391	338	341
Hemicellulose (g/kg)	Sun	318	327	288	285	319	307
	Shade	286*	339	243*	252*	338	292*
Hemicellulose/cellulose	Sun	1.02	.093	.076	0.75	0.87	0.87
	Shade	1.18	0.96	.064	0.65	1.00	0.89
Lignin in ADF (%)	Sun	20.6	17.1	18.5	16.2	17.3	17.9
	Shade	22.0	14.5	21.7	16.3	17.4	18.4
In vitro digestibility (%)	Sun	50.0	45.0	50.9	49.5	52.1	49.5
	Shade	52.9	47.8	50.3	50.1	52.2	50.7

* Significant difference ($P < 0.05$) between sun and shade values.

Table 3. Shade effects on the voluntary feed intake, digestibility and nutrient retention of five tropical grass species by sheep.

Component		Setaria	Bahia grass	Green panic	Guinea grass	Signal grass	Mean
Voluntary feed intake							
g DM/day	Sun	376	577	480	591	528	510
	Shade	385	620	438	487	516	489
g DM/kg$^{.075}$/day	Sun	36.9	54.4	46.3	53.7	52.4	48.7
	Shade	38.7	56.4	42.3	44.3	49.6	46.3
Digestibility							
Dry matter	Sun	68.3	55.0	61.4	57.3	65.1	61.4
	Shade	65.2	60.2	57.5	54.5	63.2	60.1
Cellulose	Sun	62.0	65.5	63.9	60.7	74.1	65.2
	Shade	70.6	77.0	61.4	63.5	65.4	67.6
Hemicellulose	Sun	83.0	76.1	78.1	75.7	81.0	78.8
	Shade	76.3	75.6	77.4	67.7	84.2	76.2
Nitrogen	Sun	67.1	46.0	69.1	63.6	52.7	59.7
	Shade	76.4	42.3	64.2	65.6	73.6	64.4
Phosphorus	Sun	17.1	6.5	15.2	22.2	10.7	14.3
	Shade	6.5	18.8	1.8	21.9	30.9	16.0
Nitrogen balance							
g retained/day	Sun	2.5	1.7	4.1	3.0	0.9	2.4
	Shade	4.7*	1.4	3.3	2.7	5.5*	3.5*
% ADN retained	Sun	46.7	52.5	60.6	51.1	29.1	48.0
	Shade	57.0	47.0	55.7	44.4	61.1*	53.0
mg P retained/day	Sun	157	64	153	239	89	140
	Shade	48	201	15	197	379	168
% ADP retained	Sun	80.3	93.8	97.4	95.0	92.1	91.7
	Shade	56.3	98.5	60.0	89.3	97.6	80.3

* Significant difference ($P < 0.05$) between sun and shade values.

Table 4 shows mean values for the concentration of ammonia and volatile fatty acids in the rumen of sheep given the shaded and unshaded grass diets. Sheep given feeds from shaded pastures had significantly higher concentrations of ammonia in rumen fluid than did sheep given sun-grown feeds. The increased N content of the feed was associated with an increase in rumen ammonia concentrations

Table 4. The effects of feeding shaded and unshaded grasses on composition of rumen fluid in sheep.

		Setaria	Bahia grass	Green panic	Guinea grass	Signal grass	Mean
Ammonia (mg N/L)	Sun	57.8	33.3	58.2	65.3	64.1	55.7
	Shade	88.6*	46.9	74.3	81.8	73.0	72.9*
Volatile fatty acids							
Total (mmol/L)	Sun	45.9	39.6	44.6	50.7	57.7	47.7
	Shade	41.0	51.7	40.1	52.7	47.2	46.5
Acetic acid (mmol/mol total)	Sun	776	770	760	791	791	778
	Shade	742	751	731	777	745	749*
Propionic acid (mmol/mol total)	Sun	165	162	155	150	146	156
	Shade	173	171	169	169	178	172*

* Significant difference ($P < 0.05$) between sun and shade values.

which in turn enhanced microbial protein flow to the intestines thereby improving N supply and retention. It was also found that the fermentation patterns in the rumen of sheep fed shaded pastures changed, with propionic acid levels increasing and acetic acid levels decreasing. These changes are also consistent with the fermentation of more protein in the rumen.

Experiment 2

In the second experiment a range of different grasses was grown and harvested at intervals from establishment. Table 5 reports some preliminary results showing the effects of shade on growth and composition. As there were no significant effects on individual grasses only the overall species means are presented for each parameter. Herbage yield was initially depressed by shade. However, by harvest 4, yield was slightly better, albeit not significantly, in shaded plots. This may have been an early indication of the shade–induced growth response following 'run down' of the initial fertilizer N application. Shading of N-deficient soils appears to stimulate mineralisation of N from organic N reserves (Wilson et al. 1990).

Shade decreased the dry matter content and increased the N concentration of herbage as expected (Table 5). However, there was no consistent effect of decreasing light level on leaf and stem proportions, or on hemicellulose, cellulose, or lignin percentages. There was a small non-significant decrease in soluble carbohydrates and a decrease in in vitro dry matter digestibility at harvest 2, only. These results indicate that there are equivocal effects of shade on chemical composition of forage species.

Conclusions

The feeding trials conducted to date have not found any significant effect of shading to 50% on the intake and digestibility of five grass species. While there were some small changes in the chemical composition of the plant cell walls, these changes do not appear to alter fibre digestibility. The major consistent change observed was in the N content of the plant material under shade, and this can be translated to improvements in nutritive value, particularly where the N content of the sun-grown plant is low. Differences between species were much larger than any shade effects observed in these studies and it is recommended that further sun-shade comparisons be discontinued in favour of species comparisons grown under shade. However, it seems possible that detrimental effects may still be produced with some species in shade or, as indicated in experiment 2, when grasses are subjected to very low light levels such as at the 30% or even lower light levels which may occur under mature rubber plantations.

There is a need now to investigate the nutritive value of forage and browse legumes grown in shade, especially because leguminous plants are more likely to develop anti-nutritive factors than grasses.

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Table 5. The effects of varying light transmission on the mean yield, dry matter content, leaf proportion, nitrogen concentration, soluble carbohydrate, hemicellulose, cellulose, and lignin fractions, and in vitro digestibility of six grasses.

Parameter	Light level (% light transmission) 100	68	50	30
Dry matter yield (t/ha)				
Harvest 2	1.90a	1.10b	1.05b	0.67b
Harvest 3	4.14a	3.10b	2.36c	2.10c
Harvest 4	4.28	6.07	5.42	5.98
Dry matter content (%)				
Harvest 2	15a	13b	13b	11c
Harvest 4	33	33	28	27
Green leaf (% DM)				
Harvest 2	73	75	74	71
Harvest 3	33a	45b	44b	41b
Nitrogen concentration (% DM)				
Harvest 2	2.23	21.6	2.21	2.56
Harvest 4	0.86a	0.92ab	1.02bc	1.08c
Soluble carbohydrate (% DM)				
Harvest 2	10.7	12.4	9.9	9.6
Harvest 4	12.3	11.9	12.2	11.7
Hemicellulose (% DM)				
Harvest 2	33.1	32.3	31.2	30.6
Harvest 4	34.9	34.7	33.6	33.5
Cellulose (% DM)				
Harvest 2	26.8	29.1	26.9	27.0
Harvest 4	23.7	28.2	25.6	27.3
Lignin (% DM)				
Harvest 2	9.6	9.4	10.4	11.5
Harvest 4	14.3	11.7	14.1	13.9
In vitro dry matter digestibility (% DM)				
Harvest 2	68.5a	68.9a	67.4ab	64.3b
Harvest 4	58.6	58.5	60.0	57.6

Means in rows followed by different letters are significantly different ($P < 0.05$).

Intake and Digestibility of Some Forages for Shaded Environments

D.A. Kaligis* and S. Mamonto*

Abstract

A series of pen feeding trials was carried out with goats at Manado, North Sulawesi, Indonesia. Six and 12-week-old regrowth of *Panicum maximum* cv. Riversdale, *Setaria sphacelata* cv. Splenda, *Paspalum wettsteinii, Paspalum dilatatum, Paspalum conjugatum* (local), *Axonopus compressus* (local), *Calopogonium mucunoides* and *Arachis pintoi* cv. Amarillo were fed fresh to goats and their morphology, intake and digestibility were measured.

Leaf percentage was highest in the 6-week-old regrowth of *P. wettsteinii*. The lowest leaf proportion was recorded for *S. sphacelata* in both the 6- and 12-week-old regrowth. Digestibility was highest in *A. compressus* (> 70%), followed by *A. pintoi, C. mucunoides* and the 6-week-old regrowth of *S. sphacelata*. Voluntary intake was highest in *A. pintoi*, followed by *A. compressus* and *C. mucunoides*. The lowest intake was recorded for *S. sphacelata*.

A number of species has been reported to be suitable for growing under plantation crops. Shelton et al. (1987) and Rika et al., Kaligis and Sumolang, Ng (these Proceedings) report the continuing evaluation of new germplasm for shaded environments. Selection criteria include factors such as persistence under cutting or grazing and high yield in shade. However, the value of these plants as feed for ruminants also needs to be determined. Species must be acceptable to animals, have a high nutritive value, and should be non-toxic.

This experiment was conducted to study the nutritive value in terms of digestibility and voluntary intake of promising grasses and legumes which were identified in a concurrently-run evaluation of forages for coconut plantations in North Sulawesi.

Materials and Methods

A series of pen feeding trials were carried out with goats at Manado, North Sulawesi, Indonesia, between 1988 and 1990. The climate in Manado is wet tropical with a well distributed, average annual rainfall of 2770 mm and average mean monthly maxima and minima temperatures of 33.5/21.5°C and 29.0/21.9°C for summer and winter respectively.

Plots of promising forages were established under a stand of old coconuts with a light transmission of 75% PAR. The forages planted included the grasses *Panicum maximum* cv. Riversdale, *Setaria sphacelata* cv. Splenda, *Paspalum wettsteinii, Paspalum dilatatum, Paspalum conjugatum* (local) and *Axonopus compressus* (local), and the legumes *Calopogonium mucunoides* and *Arachis pintoi* cv. Amarillo.

Plots were cut to a height of 5–20 cm (depending on growth habit) at 6 and 12 weeks prior to feeding period to obtain material of 'young' and 'old' regrowth. Each feed was fed *ad libitum* (10–20% above intake) and fresh to four goats housed in individual pens. As eight goats (same sex, age and approximate weight) were available for the trial, two feeds were simultaneously processed. It was assumed that there was very little difference between feeding periods since the climate is uniform. Goats were drenched regularly to control parasites, and water and salt were available at all times.

Each feed was fed for 3-4 weeks and feed intake and amount of refusals and faeces were recorded for the last seven days each feeding period. At the time of this workshop, the trial had not been completed and therefore some data sets are not complete.

Results and Discussion

The morphological characteristics of the 6-and 12–week-old regrowth are presented in Table 1. *Setaria sphacelata* had the lowest proportion of leaf of all species; the highest proportion was recorded for *P. wettsteinii* in the 6-week-old regrowth. There was a large difference in the proportion of leaf between the 6-and the 12–week-old material of this latter species, while there was little difference in other species. The

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proportion of stem usually increases with increasing age of forage plants (Whiteman 1980). A high proportion of dead material was present in the 12-week-old regrowth of *P. dilatatum* and *A. compressus*, which indicates that this regrowth period was too long for maximum yield. With the exception of *C. mucunoides*, none of the species had a large proportion of flowers or inflorescences. The small amount of flowering and seed production may be related to the close proximity to the equator.

The dry matter digestibility of the various feeds, aged 6 and 12 weeks, is presented in Table 2. *Axonopus compressus* had the highest digestibility of all species despite the regrowth period of 12 weeks and the large proportion of dead material in the feed. The relatively high nutritive value of *A. compressus* has been reported previously (Samarakoon et al. 1990). The second-highest digestibility was recorded for the 6-week-old regrowth of *S. sphacelata* and this was followed by *A. pintoi* and *C. mucunoides*. The 12-week-old material of *P. maximum* had the lowest digestibility of all species. In all three cases, where data for both the 6-and 12-week-old material were available, the digestibility of the younger material was higher than that of the older material. This effect of age of regrowth on digestibility of forages is widely reported (Whiteman 1980).

The voluntary intake of the legumes and especially that of *A. pintoi* was higher than the intake of the grasses (Table 2). The exception was *A. compressus*. The higher intake of legumes, compared to grasses, despite similar digestibility, has been previously reported (Thornton and Minson 1973). The intake of the 12-week-old regrowth of *S. sphacelata* was particularly low and much lower than that of 6-week-old regrowth. This occurred despite the similar proportion of leaf in the 6-and 12-week-old regrowth of this grass.

Table 2. Dry matter digestibility (%) and voluntary intake (g/day) of 6-and 12-week-old regrowth of various forages, fed fresh to goats.

Species	Age of regrowth (weeks)	Dry matter digestibility	Intake (g/day)
Panicum maximum	6	51.7	311
	12	43.7	321
Setaria sphacelata	6	68.2	282
	12	52.2	185
Paspalum wettsteinii	6	57.3	359
	12	50.8	309
Paspalum dilatatum	6	–[1]	–
	12	61.7	299
Paspalum conjugatum	6	–	–
	12	49.7	264
Axonopus compressus	6	–	–
	12	74.9	383
Calogogonium mucunoides	6	65.5	381
	12	–	–
Arachis pintoi	6	67.5	417
	12	–	–

[1] The feeding trials had not been completed at the time of the workshop

Table 1. Morphological characteristics of 6-and 12-week-old regrowth of various cut forages prior to feeding to goats for nutritive value determinations.

Species	Age of regrowth (weeks)	% in Dry Matter: Leaf	Stem	Inflorescence	Dead material
Panicum maximum	6	53	45	1	2
	12	52	44	1	4
Setaria sphacelata	6	33	63	0	3
	12	33	64	0	3
Paspalum wettsteinii	6	63	31	0	6
	12	43	45	2	10
Paspalum dilatatum	6	–[1]	–	–	–
	12	41	25	0	34
Paspalum conjugatum	6	–	–	–	–
	12	41	37	3	19
Axonopus compressus	6	–	–	–	–
	12	43	17	3	37
Calogogonium mucunoides	6	44	45	12	0
	12	–	–	–	–
Arachis pintoi	6	45	47	0	8
	12	–	–	–	–

[1] The feeding trials had not been completed at the time of the workshop.

Conclusions

Of the legumes, *A. pintoi* had both a high digestibility and a high voluntary intake. Among the grasses, *Axonopus compressus* had a particularly high digestibility and voluntary intake. Of the introduced grasses, *S. sphacelata* had a high digestibility in the young regrowth but low intake, especially in the 12-week-old regrowth.

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Productivity of Cattle under Coconuts

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Abstract

In contrast to many other plantation crops, permanent integration of cattle under coconuts is feasible because of the open canopy characteristics of coconuts. Factors such as soil type, fertilizer strategy and stocking rate affect animal productivity, and liveweight gains are reduced in plantations with low light transmission. Liveweight gains are enhanced by the planting of improved forages, particularly legumes. Long-term sustainability of improved pastures under coconuts will depend on the use of grasses, which will not only persist under low light and regular grazing but will keep pastures relatively free from the ingress of weeds.

A unique quality of coconuts, compared to most other plantation crops, is that they can be intercropped on a semipermanent basis. Unlike rubber and oil palm, the light environment under coconuts is relatively constant and bright over the life of the crop which can be as long as 60 – 80 years. It is therefore possible to establish a permanent pasture and animal husbandry infrastructure and to develop a stable beef production enterprise with a consistent output of animal product. Only during the very early life of new coconut plantations (< 5 years) will grazing cattle damage the young palms (Reynolds 1988).

In order to successfully develop a coconut–beef enterprise, a knowledge of the costs of inputs and value of returns is required so that detailed planning can be undertaken, especially if outside finance is required. While development costs of pastures under coconuts are likely to be similar to that for pastures planted in full sunlight, the levels of beef production obtained under coconuts may be somewhat less as the productivity and persistence of pastures will be modified by a reduced light environment.

The objective of this paper is therefore to review the data available on levels of beef production under coconuts and to estimate the influence of the reduced light environment on productivity and sustainability.

Productivity Levels

A summary of liveweight gain data obtained under coconuts is given in Table 1. Animal productivity varied from a low of 44 kg/ha (Manidool 1983) to a high of 505 kg/ha (Rika et al. 1981); this variation was associated with a number of management and environmental differences across the locations although the relative influence of these is difficult to assess. There was variation in light transmission, pasture species planted, soil type, fertilizer strategy, and stocking rate employed. These are now discussed.

Plantation palm density, and therefore light transmission, was clearly an important factor as liveweight gains were highest in the more open plantations where forages received the highest percentage of ambient radiation (Table 1). A comparison of the productivity of shaded and full-sun pastures is possible in Solomon Islands where grazing trials were conducted concurrently in the two light environments on similarly fertile soils although at different locations. The mean optimum stocking rates and maximum liveweight gain per ha over three years and for several pasture types were 4.0 cattle/ha and 467 kg/ha for full-sun pastures (Watson and Whiteman 1981a), and 3.7 cattle/ha and 352 kg/ha for pastures under coconuts (Watson and Whiteman 1981b).

The species present in understorey forages was also important. Both Reynolds (1981) and Manidool (1983) demonstrated substantial improvement in liveweight gain from improved over natural forages indicating the desirability of replacing natural with improved forages for maximum animal production. Although this conclusion was apparently not supported by the results of some other studies (Robinson 1981; Watson and Whiteman 1981b; Smith and Whiteman 1985), in all these cases there was a substantial proportion of naturalised legume in the pasture which clearly improved its quality for grazing animals.

The importance of legumes to pasture quality under coconuts was demonstrated in Vanuatu where low liveweight gains were reported for animals grazing

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Table 1. A summary of cattle liveweight gain data from grazing experiments under coconuts.

Country	Pasture	Light transmission (%)	Liveweight gain (kg/ha)	Stocking rate (b/ha)	Reference
Solomon Islands	natural	60	235–345	1.5–3.5	Watson and Whiteman 1981b
(2900 mm/year)	improved	60	227–348	1.5–3.5	
	natural	62	219–332	1.5–3.5	Smith and Whiteman 1985
	improved	62	206–309	1.5–3.5	
Western Samoa	natural	50	148	1.8	Reynolds 1981
(2929 mm/year)	improved	50	225–306	1.8–2.2	
	natural	70–84	127	2.5	Reynolds 1981
	improved	70–84	273–396	2.5	
	natural	70–84	401–466	4.0	Robinson 1981
	improved	70–84	421–693	4.0	
Indonesia (1709 mm/year)	improved	79	288–505	2.7–6.3	Rika et al. 1981
Thailand	natural	n.a.	44	1.0	Manidool 1983
(1600 mm/year)	improved	n.a.	94–142	1.0–2.5	
Vanuatu (1500 mm/year)	improved	n.a.	175	1.5	Macfarlane and Shelton 1986

pure *Stenotaphrum secundatum* (buffalo grass) pastures (Macfarlane and Shelton 1986). Subsequent measurements of liveweight gains of smallholder cattle grazing buffalo grass containing the naturalised legumes *Desmodium canum* and *Vigna hosei* showed average gains of 0.7 kg/head/day over a 100-day measurement period (B. Mullen, pers. comm. 1990).

Stocking rate was also an important variable in animal production although only four of the experiments reported comparative liveweight gain data obtained at different stocking rates. These were analysed using the stocking rate model of Jones and Sandland (1974), as follows:

liveweight gain/head $= a - bx$, and
liveweight gain/ha $= ax - bx^2$,

where x = stocking rate; a = y-axis intercept; b = slope; and $a/2b$ = the optimum stocking rate.

In interpreting these models, it is emphasised that the optimum stocking rates calculated are simply the points at which liveweight gain per ha is maximised over the period of the experiment, and do not necessarily represent the optimum stocking rate where pasture persistence and/or economic returns are maximised. Extrapolation and interpretation of results much beyond the measured points should be done with caution.

Figures 1 – 4 demonstrate the importance of stocking rate effects on liveweight gain per ha and per head. Highest liveweight gains per ha were obtained in Bali at an optimum stocking rate of 8.7 cattle/ha in an open stand of coconuts (Fig. 1, Table 2). Intermediate levels were measured in Solomon Islands (Fig. 2 and 3, Table 2), whilst productivity was lowest in the experiment reported from Thailand (Fig. 4, Table 1). Some care is needed when interpreting the data from Bali as calculated optimums were outside the actual stocking rates employed (Rika et al. 1981).

As previously mentioned, productivity was clearly associated with light transmission which was highest in the Bali experiment and lowest in the Thailand experiment. Other aspects of the productivity relationships were less clear-cut. The intercept values (a), which indicate the liveweight gains of cattle at very low stocking rates and therefore reflect the quality of pastures, were highest in Solomon Islands experiments (Table 2). This may have been due to the higher legume contents of these pastures in Solomon Islands compared to the Bali and Thailand trials.

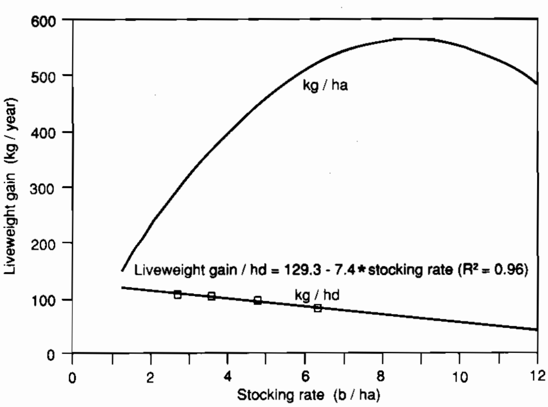

Fig. 1. Liveweight gain under coconuts in Bali (after Rika et al. 1981).

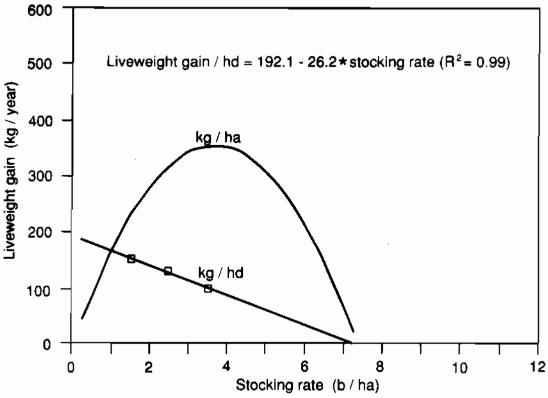

Fig. 2. Liveweight gain under coconuts in Solomon Islands (after Watson and Whiteman 1981b).

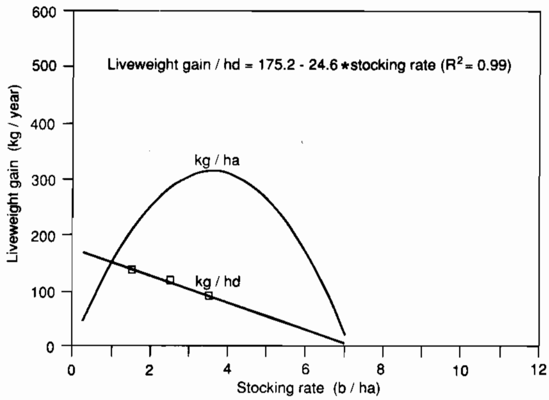

Fig. 3. Liveweight gain under coconuts in Solomon Islands (after Smith and Whiteman 1983).

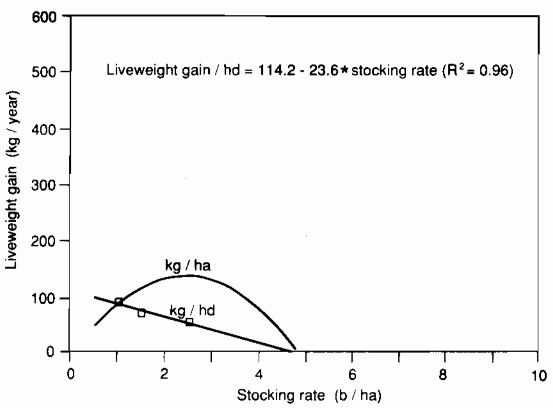

Fig. 4. Liveweight gain under coconuts in Thailand (after Manidool 1983).

On the other hand, the slope (b) of the regression line, which reflects the ability of pastures to maintain liveweight gain as stocking rate increases, was similar for the Solomon Islands and Thailand experiments (range of -23.6 to -26.2) but much lower in the Bali experiment. This latter result may have been due the replacement of the sown grasses by more grazing-tolerant grasses which were able to maintain animal productivity even at high stocking rates (Table 2) (Rika et al. 1981).

Sustainability of Production

The potential for sustainable animal production was given as one of the advantages of integration of cattle under coconuts compared with other plantation crops. However, in three of the four long-term studies quoted, the original sown grasses either did not persist or were greatly reduced as a component of the pastures (Table 2). Sown grasses tended to be replaced by more grazing-tolerant grass species such as *Cynodon dactylon* in Bali (Rika et al. 1981) and *Axonopus compressus* in Solomon Islands (Watson and Whiteman 1981b), as well as dicotyledonous weeds (Rika et al. 1981). Some of the sown legumes were initially more persistent than the grasses (e.g. *Centrosema pubescens*) but declined with time with a concomitant increase in naturalised legumes such as *Mimosa pudica* (Watson and Whiteman 1981b). These studies demonstrate that persistent grasses are required to ensure that forage systems are sustainable.

The control of unpalatable weed infestation in pastures under coconuts is another key aspect of sustainability of production (Steel, 1977), and can be related to both level of management and vigour of pastures. Good management may involve not only correct choice of pasture species to plant, but also judicious weeding of intractable weed species, fertilizer application to forages on poorer soils, and control of stocking rates to maintain vigorous pastures.

A survey of 6–10-year-old Batiki pastures (*Ischaemum aristatum*) on Malaita Island in Solomon Islands showed an average weed content of 50% and a range up to 70% depending on the adequacy of weed management and light transmission (Litscher and Whiteman 1982). Weed infestations were higher under lower light conditions, indicating the need for vigorous and persistent species tolerant of lower light levels. It is clear that non-vigorous grasses such as para grass (*Brachiaria mutica*) were associated with high weed content (Reynolds 1980), while vigorous stoloniferous species such as buffalo grass showed low weed contents and therefore greater sustainability (Macfarlane and Shelton 1986).

Table 2. An analysis of liveweight gain parameters and botanical stability in cattle grazing experiments under coconuts.

	LWG Parameters intercept (a)	scope (b)	Max LWG (kg/ha)	OPT. S.R. (kg/ha)	LT (%)	Pastures	Changes in botanical composition
Bali (Rika et al. 1981)	129.3	-7.4	565	8.7	79	*B. decumbens*, *P. plicatulum*, *P. maximum* var. *trichoglume* *D. intortum*, *L. bainesii*, *M. atropurpureum* (continuously grazed)	Reduction of sown grasses at high stocking rates, an increase in *C. pubescens S. guianensis*, grazing-tolerant species such as *C. dactylon*, *B. miliiformis*, *P. conjugatum* and *D. triflorum* and an increase in dicotyledonous weeds.
Solomon Islands (Watson and Whiteman 1981b)	192.1	-26.2	352	3.7	60	*B. decumbens*, *B. humidicola*, *B. mutica* *C. pubescens*, *P. phaseoloides*, *S. guianensis*, *C. mucunoides* (continuously grazed)	Loss of sown grasses, decline in sown legumes and an increase in *A. compressus* and *M. pudica*.
Solomon Islands (Smith and Whiteman 1985)	175.2	-24.6	312	3.6	62	*B. decumbens*, *B. miliiformis*, *C. pubescens*, *P. phaseoloides*, *C. mucunoides* (rotationally grazed)	Loss of sown grasses, sward became dominated by *C. pubescens*, *P. phaseoloides* and/or *C. mucunoides*. *M. pudica A. compressus* also increased.
Thailand (Manidool 1983)	114.2	-23.6	138	2.4	n/a	*B. decumbens*, *C. pubescens*, (continuously grazed)	Pasture composition maintained

Conclusions

It can be seen that animal production varies among plantations with liveweight gains influenced by a number of factors, particularly incident light levels. Productivity is highest in open plantations where light transmission is highest.

Animal performance is enhanced by the planting of improved forages and particularly by the presence of legumes in the pasture. However, long-term sustainability of production will depend on the use of species which will not only persist under grazing but maintain sufficient vigour to keep pastures relatively free of weeds.

In the past, studies have shown that grass species have been less persistent than legumes. The reasons for this are not well understood. New species are required which are adapted to the lower light regime of coconut plantations and are able to persist under regular defoliation. Compatible legumes will be a prerequisite if high liveweight gains are to be achieved.

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Cattle Productivity under Oil Palm in Malaysia

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Abstract

Young oil palm plantations provide a favourable environment for cattle production. The undersown cover crops provide good quality forage with a high metabolisable energy and crude protein content. In a grazing trial under oil plam, stocking rate declined with time from three kedah-kelantan cattle to one per ha as tree age increased from three to eight years. Animal production dropped from 289 to 69kg liveweight gain/ha over this period.

RUMINANT production in Malaysia has not advanced significantly in the last two decades. In 1988 it dropped from self-sufficiency to levels of sufficiency of 34% in beef, 8% in mutton and 5% in milk, despite apparent growth in production of 6.3%, 3.6%, and 8.4%, respectively.

Most of the ruminants in the country are owned by smallholder farmers and the major constraint to increased livestock production is the difficulty in providing feed of sufficient quantity and with adequate nutrient composition throughout the year, especially during peak cropping periods when most of the land is under cultivation. Good agricultural land in Malaysia is usually intensively cropped and is not available for fodder production.

With the implementation of double-cropping of paddy in the mid-1960s, there has been a shift of ruminant production from granary areas and traditional villages to the plantations. The shift is expected to accelerate, making tree-crop plantations the new centre for livestock production in Malaysia.

Of the 45 560 t of ruminant meat consumed in Malaysia in 1988, 85% was beef, making cattle the main animal species for meat production. There are currently about 1.8 million ha of oil palm available in the country and although cattle are regularly grazed under coconut plantations, research on cattle–oil palm integration started only in the early 1970s. The objectives of this paper are to highlight progress made in research and development of cattle production under oil palm in relation to the feed resources and the effects of animal grazing on the plantation crop.

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Forages Resources under Oil Palm

Under normal estate conditions, the vegetation biomass accumulates to gain full ground cover between one and two years after planting of oil palms. It reaches a peak yield of 5.5–9.5 t DM/ha (if not weeded) around years three and four before canopy closure. In a well managed oil palm plantation, intensive weeding programs start immediately after planting the oil palms. The aim is to control competitive weeds such as *Imperata cylindrica, Chromolaena odoratum, Asystasia intrusa* and sedges, to facilitate the establishment of leguminous cover crops. Some oil palm estates may tolerate the existence of less competitive weeds such as *Paspalum conjugatum* and *Ottochloa nodosa*, but many do not.

Due to the continuous growth of palm, illumination through the fronds is rapidly reduced which in turn reduces the dry matter yield and changes the botanical composition of the forages available. Sun-loving species will eventually disappear from the understorey vegetation. Recent studies of Chen and Othman (1983) and Wan Mohamed et al. (1987) show a rapid decline in legume composition and an increase in proportion of grasses and broadleafed weeds as oil palms age (Fig. 1). By year six, legumes accounted for less than 10% and grasses increased to more than 60% of the total dry matter yield.

There are more than 60 species recorded as contributing to effective forage yield under normally managed oil palm plantations. Of those, 70% are palatable to ruminants.

Nutritionally, forage resources under oil palm are varied and rich in protein, especially in the early years, because of the high legume content. The crude protein of grasses under most plantation ranges from 8 to 17%, broadleaved weeds from 13 to 16%, and palatable weed species such as *Mikania cordata* and *Asystasia intrusa* from 15 to 22%, while the legumes

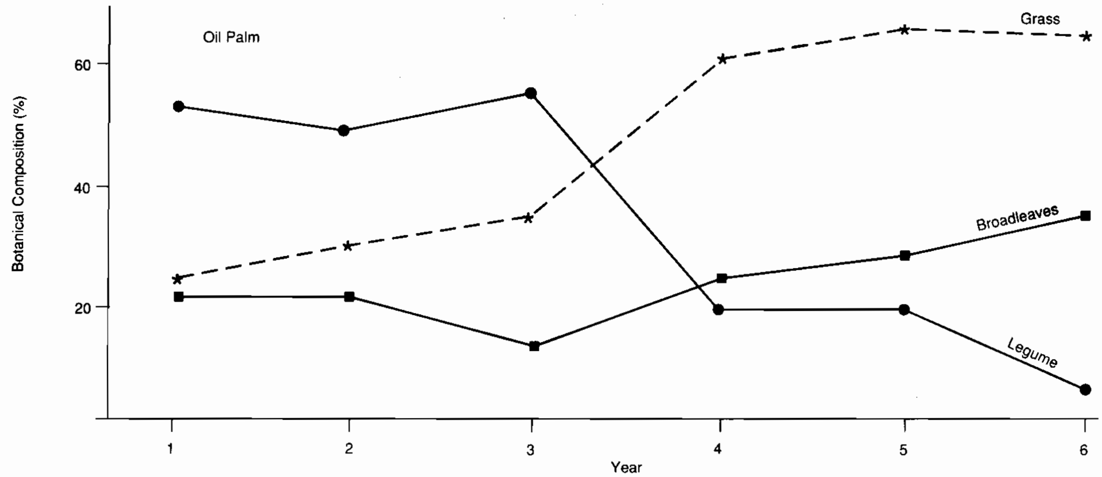

Figure 1. Botanical composition of ground vegetation in relation to age of oil palm.

range from 15 to 28%. Further, the estimated energy concentration for grasses under plantations varies from 7 to 10 MJ metabolisable energy (ME) per kg DM, while broadleaved species and ferns appear to have values superior to the grasses (Lane and Mustapha 1983). Thus the nutritive value of natural herbage under plantations is comparatively high, especially when total nutrient availability from broadleaves species such as *A. intrusa* and cover crop legumes is considered.

Effects of Grazing Cattle

The main objective of introducing cattle into oil palm plantations is to control the excessive growth of vegetation which may compete with the oil palm. However, if introduced too early, the animals may cause severe damage to young oil palms.

An experiment was established in a newly planted oil palm plantation to evaluate the time of introduction of cattle on severity of damage to the palms (Mohd. Sukri et al. 1982). Guinea grass and different leguminous cover crops were established under the palms. The results indicated that it is possible to introduce cattle for free grazing at a minimum palm age of one year. Frond damage was unavoidable since palms were relatively small at that early stage, yet the effects of grazing on flowering and fruiting of the palms were almost negligible. However, there was a tendency for earlier flowering and fruiting of palms in the non-grazing treatment.

The authors concluded that since damage to young photosynthesising fronds may disturb palm growth and delay maturity, it may be advisable to delay introduction of grazing animals another 6–12 months, i.e. at a palm age of 1.5–2 years. It is suggested that an initial stocking rate of 550–750 kg liveweight biomass/ha (2-2.8 cattle/ha) (depending upon the availability of ground cover) should be maintained for the first six months after introduction until full ground cover is achieved, and a slightly higher stocking rate can then be imposed during the early stages of the oil palm plantation.

Frond damage is often noticed even in older plantations (3-4 years). Othman et al. (1985) reported that the number of fronds nibbled by grazing cattle increases when greater grazing pressure is imposed (Table 1). However, fresh fruit bunch (FFB) yield was affected only when frond damage reached 57% at the high stocking rate of 3 cattle/ha in four-year-old oil palm. It was observed that the majority of the damaged fronds were in the lower part of the canopy and had already reached senescence. Hence it may be that cattle nibbling of fronds may serve a useful pruning effect on the palm.

Table 1. Frond damage of oil palm grazed by cattle at different stocking rates (after Othman et al. 1985).

	Stocking rate (head/ha)	Percentage of fronds damaged (%)
(a) 3-year-old palm		
	1	22
	2	37
	3	45
(b) 4-year-old palm		
	1	22
	2	41
	3	58

Animal Performance

The performance potential of cattle grazing forages grown under the plantations is poorly documented. In an experiment in Malaysia, comparison was made of two systems of grazing (rotational and continuous) cattle on forages under oil palm and improved tropical pastures in the open. The cattle used were young male Kedah-Kelantan (KK). Pastures in the open comprised nitrogen-fertilised guinea grass, while cattle under plantation grazed natural herbage available under 2-year-old oil palm. No supplementary feed was given except mineral lick. Fertilizers applied to the improved full-sun guinea pastures were 300 kg N, 50 kg P and 100 kg K/ha/year, but forage under oil palm was not fertilised. The performance of animals is shown in Table 2.

Daily liveweight gain of cattle grazing at one animal/ha under oil palm was higher than those grazing improved pastures in the open. This resulted in earlier marketing of animals by 4–6 months. Better animal performance under oil palm is believed to be due to the high quality of the multi-species feed resources, with high energy and protein contents, and to the lower stocking rate employed. Liveweight gain of cattle grazing at two animals/ha under oil palm was limited by forage availability. While daily liveweight gains of cattle grazing under oil palm were high, the overall productivity per ha was low when compared to open pastures (Table 2).

Liang et al. (1988) and Liang and Samiyah (1988) reported that the maintenance requirement of metabolisable energy for KK cattle was 494 KJ ME/kg $^{0.75}$, while the intake of cattle grazing 10-week-old guinea grass was only 477 KJ ME/kg $^{0.75}$ or 1.9% of bodyweight. By contrast, the dry matter intake of cattle grazing natural forage under oil palm was 2.3% of bodyweight or 1.4 times maintenance requirement.

The more favourable climatic environment of plantations such as the lower ambient temperature (1–3°C lower) and the small increase in relative humidity (1-6% units higher), as summarised by Wilson (1988), may have improved the performance of animals under plantations. Similar results, in which better animal performance under oil palm (Table 3) was obtained compared with other systems such as bunds and roadside and open-improved pasture, were reported by Dahlan and Mohd. Ariff (1987).

Effects of Age of Palms on Cattle Productivity

The productivity and optimal stocking rate of cattle under oil palm depends upon the availability of forage which declines with incident radiation as the palms grow older. Othman et al. (1985) and Wan Mohamed et al. (1987) reported daily liveweight gains of 264, 159, 390, 169 and 188 g/head, equivalent to 289, 174, 284, 123 and 69 kg/ha/year, from KK cattle under oil palm as the tree age increased from 1 to 5 years respectively. These liveweight gains were achieved under initial stocking rates of 3 (years 1+2), 2 (years 3+4) and 1 (year 5) KK cattle/ha. Final stocking rate may be as low as 0.3 head/ha as feed resources become scarce. These cattle liveweight production levels compare with figures of 337, 244 and 319 g/head/day, equivalent to 226, 355 and 465 kg/ha/year obtained over three years from improved pastures in the open (Eng et al. 1978).

Reproductive Performance

Wan Mohamed et al. (1987) investigated the reproduction of 300 KK cattle grazing on naturally occuring vegetation under 10–15-year-old oil palm

Table 2. Liveweight gain comparison of Kedah-Kelantan (KK) cattle grazing under oil palm and in the open (C.P. Chen - unpublished data).

Treatment	Daily liveweight gain (g/head) Year 1	Daily liveweight gain (g/head) Year 2	Liveweight gain (kg/ha) Year 1*	Liveweight gain (kg/ha) Year 2
(a) Guinea pasture in the open				
Rotational grazing at 6 KK/ha	330	203	666	444
Continuous grazing at 6 KK/ha	361	253	726	552
(b) Native pasture under oil palm				
Continuous grazing at 1 KK/ha	380	283	128	103
Continuous grazing at 2 KK/ha	320	228	214	166

* Year 1 was 336 days grazing.

Table 3. Performance of crossbred cattle under three different feeding systems (Dahlan and Mohd Ariff 1987).

Crossbred cattle	Liveweight gain (g/head/day)		
	Open improved pastures	Irrigation bunds and roadsides	Under oil palm plantations
Kedah-Kelantan (KK)	186	88	249
Hereford × KK	302	95	306
Brahman × KK	203	121	249
Friesian × KK	234	138	205

(light transmission 10%) in a Federal Land Development Agency (FELDA) scheme over two years. The average conception rate of cows, with access to fertile bulls year-round, was 52%, and the percentage of cows with and without corpus luteum was 25 and 23, respectively. There was an increasing trend of anoestrus animals towards the end of the second year, with values from 10 to 41%. The authors attributed this effect to the low forage availability at that time. The mean herbage yield on-offer recorded over the period was only 355 kg DM/ha, comprising 37% native grasses (mainly *Axonopus compressus*), 27% ferns, 12% *Asystasia intrusa*, 20% woody shrubs and some other species. At the end of the second year the stocking rate was recorded at 0.75 head KK/ha, giving a total liveweight biomass of 95 kg/ha.

Conclusion

The vast land area of immature oil palm plantation containing 5.5–9.5 t DM/ha of green ground covers is a good niche for beef cattle production. The oil palm plantations provide not only a favourable climatic environment but also good quality forage with a high metabolisable energy and crude protein content for animal production.

Green vegetation under young oil palm comprised approximately 60% grasses, 20% legumes and 20% broadleafed weeds.

Cattle can damage young oil palm. Frond nibbling is unavoidable but it can be minimised by not introducing grazing animals until the crop age reaches 1–2 years. It was observed that oil palm frond damage within a range of 30–40% can be accepted with no significant loss of yield. The animals effectively pruned the palms.

The optimum stocking rate declined with time from three KK cattle to one per ha as tree age increased from three to eight years. Animal liveweight production dropped from 289 to 69 kg/ha over the same period. There was a problem of low reproduction of cattle when the palm canopy closed (about 10% sunlight) and there was little forage available.

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Stocking Rate Effect on Sheep and Forage Productivity under Rubber in Malaysia

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Abstract

Two sheep-grazing studies were initiated on the Malaysian Rubber Research Institute's Research Station at Sungei Buloh, designed to investigate the influence of grazing at various stocking rates under maturing rubber on forage composition and production and animal productivity. One trial was under immature rubber (three years old) and the other under mature rubber (seven years old).

After 12 months of grazing under immature rubber, forages were able to sustain 17 sheep/ha and produce just under 400 kg/ha/year of liveweight gain. However, this optimum stocking rate declined as the canopy matured; in the 7-year-old rubber, sustainable stocking rate was only 2 sheep/ha.

At higher stocking rates, palatable species such as *Pueraria phaseoloides*, *Paspalum conjugatum*, *Mikania micrantha* and *Asystasia intrusa* declined while unpalatable species such as *Calopogonium caeruleum* dominated the swards.

In recent years, there has been a dramatic shift in the Malaysian sheep industry from backyard subsistence farming to larger-scale integrated sheep farming under plantation crops. This development is a logical direction for commercial sheep production in Malaysia. The catalyst for further development of the sheep industry will be the active participation of government agencies such as Federal Land Development Authority (FELDA), Rubber Industry Smallholder Development Authority (RISDA), and Federal Land Consolidation and Rehabilitation Authority (FELCRA). In these land development schemes, flocks of 300–500 ewes are now quite common, with some having close to one thousand or more ewes. These large flocks are intensively managed, and often supplemented with palm kernel cake (PKC), but poor understanding of pasture management has sometimes led to overgrazing resulting in poor animal performance.

There is also a lack of understanding of the complexity of plant and animal interactions in long-term sheep raising under maturing rubber. The grazing sward under rubber consists mainly of naturalised grasses, broadleafed weeds and sown leguminous covers which exhibit a variable growth pattern with low forage availability during the dry season but particularly as the canopy closes under maturing rubber. This has caused problems in terms of setting correct stocking rates, maintaining forage productivity and achieving the desired level of weed control. An experiment was therefore designed with the following objectives: 1) to study the influence of sheep grazing on forage composition and production and weed control under maturing rubber, and 2) to study the stocking rate and liveweight gain potential of sheep under a maturing rubber plantation.

Materials and Methods

Two grazing trials were conducted concurrently between October 1988 and May 1990 at the RRIM Experimental Station, Sg. Buloh, in Central Malaysia. The first experiment was conducted under 7-year-old mature rubber, the second under 3-year-old immature rubber. The two sites were chosen to provide information on the upper and lower limits of forage production and animal productivity under rubber. The mean annual rainfall at Sg. Buloh (1977–89) is 2190 mm, and this rainfall is well distributed with a minimum of 110 mm/month during the drier months of June and July.

The main treatment was stocking rate (SR) under a continuous grazing system. For the immature rubber

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trial, the SR treatments were 4, 6, 8, 10, 12 and 14 sheep/ha, while for the mature rubber, lower SR treatments of 2, 4, 6 and 8 sheep/ha were imposed.

Each treatment paddock was stocked with three weaned male crossbred lambs aged 3–4 months. Stocking rate was obtained by varying the paddock size. The lambs selected consisted of F1 and F2 50% Dorset × Malin crossbreds which attained a weaning weight of 12–14 kg.

The grazing period for each draft of lambs was about six months and evaluations were based on two drafts for the immature rubber trial and three drafts for the mature rubber trial. In the case of the mature rubber, continuous grazing was possible only for the SR-2 treatment, while for the SR-4, SR-6 and SR-8 treatments, intermittent grazing was adopted as the forage 'crashed' after 2–3 months of grazing.

The sheep were allowed six hours of grazing from 8.00 a.m. until 2.00 p.m., after which they returned to the shed until the following morning. In the shed, supplementary feeding of palm kernel cake (PKC) at 100 g/head was provided daily.

Fresh water and mineral licks were also provided ad lib. Sheep were drenched at monthly intervals in order to ensure that they were free from endoparasites. Animal weighing was carried out weekly in the mornings before animals were taken out to graze.

The rubber trees in the experimental paddocks were fertilised using standard management practices. However, weed control measures (herbicide spraying and hand-weeding) were limited to along the tree rows or the tappers' paths whenever the vegetation was found to hinder tapping operations. As a general practice, herbicide spraying around the young rubber trees (circular spraying) was also carried out before fertilizer application.

The CSIRO Botanal Technique (Jones and Tothill 1985) for estimating green dry matter yield and botanical composition was adopted. The technique involved visual estimation of total green yield in each quadrat using a score between 1 and 10 which was subsequently calibrated against a standard. The standard was set by taking forage samples from 15 quadrats with scores ranging from 1 to 10; these samples were cut, dried and weighed to determine the dry matter yields. To facilitate a realistic and systematic scoring of undergrowth, a series of quadrats forming a band extending from the tree row through the interrow and up to the next tree row were sampled.

Results and Discussion

Forage sustainability under rubber

The results of the concurrent grazing trials carried out under both immature and mature rubber (based on 12 and 18 months of study, respectively) clearly demonstrated the upper and the lower limits of forage productivity and sustainability under rubber.

Forage availability declined markedly in all treatments with the highest reduction in SR-14 (Fig. 1). Despite this reduced yield, continuous grazing was possible in all the treatments for the entire 12-month evaluation period. An exception was the first draft of animals stocked in the SR-12 treatment which were withdrawn for four months as they refused to graze the *Calopogonium caeruleum* dominated sward. However, the second draft of sheep grazed *C. caeruleum* without problem.

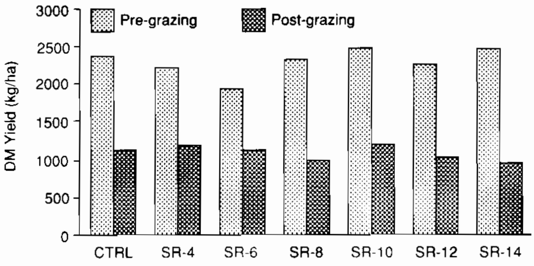

Fig. 1. Changes in dry matter yield of forage under immature rubber over a 12-month period at seven different stocking rates.

In the mature rubber, only the low stocking rate of 2 sheep/ha was sustainable. The limiting factor was the low forage availability at the higher stocking rates (Fig. 2). Grazing in the SR-4, SR-6 and SR-8 treatments was intermittent since these treatments 'crashed' after 2–3 months of grazing. The post-grazing values shown in Fig. 2 represent the standing biomass after the early removal of the third draft of sheep. The number of grazing days achieved and the actual final stocking rates per treatment are shown in Table 4.

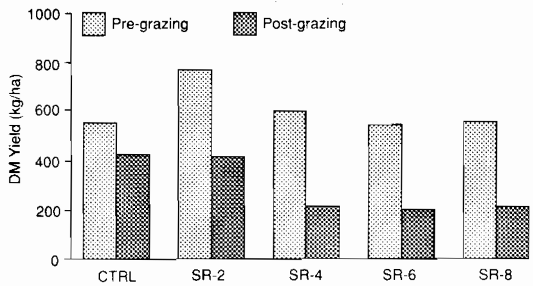

Fig. 2. Changes in dry matter yield of forage under mature rubber over an 18-month period at five different stocking rates.

In the ungrazed control plots, a similar reduction in dry matter yield was observed. The seasonal rainfall pattern and declining light regime were the major factors contributing to this rapid decline. Under immature rubber, photosynthetically active radiation light transmission dropped from 86% of ambient PAR at the beginning of the trial to 59% of ambient PAR 12 months later. Under mature rubber, the drop in light transmission was from 22% of ambient PAR to 18% at the end of the trial period.

Changes in botanical composition

The increasing dominance of grasses and broadleafed weeds over legume cover crops under maturing rubber has been well documented. However, with grazing sheep present, it was observed that the persistence and dominance of species was mainly dependent on their palatability. Animal selectivity strongly influenced the dominance of species.

Under immature rubber (Table 1), there was a decrease in the proportion of palatable species, namely, *Pueraria phaseoloides*, *Paspalum conjugatum*, *Mikania micrantha*, and to a lesser extent *Asystasia intrusa*, due to animal selectivity. In contrast, there was an increase in the proportion of *C. caeruleum* (a less palatable species) in all stocking rate treatments. Continuous grazing led to dominance of *C. caeruleum* (93–99%) in all stocking rate treatments except SR-4. The role of sheep grazing in legume purification is a great asset in the undergrowth management of rubber as substantial cost savings can be realised due to reduced weeding, while at the same time there is a benefit of nitrogen fixation by the legume covers to boost the growth of rubber. Cost savings in weed control of as much as 38% under mature rubber have been reported by Tajuddin et al. (1990).

Under mature rubber, the proportion of *C. caeruleum* was reduced in the control as well as in all grazing treatments (Table 2). This result showed that, regardless of the effects of sheep grazing, the succession and replacement of legumes by grasses and broadleafed weeds under maturing rubber was inevitable. The succession from legume covers to grasses and broadleafed weeds as rubber approached 3–5 years was also reported by Chee and Faiz (these proceedings).

There was an increase at the higher stocking rates in *Cyrtoccum oxyphyllum* at the higher stocking rates, which is known to be less palatable to sheep. In contrast, the proportions of preferred species such as *P. conjugatum* and *M. micrantha* decreased at the higher stocking rates. This result indicated the importance of maintaining low stocking rates to avoid undesirable changes in species composition. *Asystasia intrusa* was initially present only in the SR-2 treatment, where it increased with time but later also invaded the control plots.

Animal productivity

As stocking rate increased from four to 14 sheep/ha under immature rubber, the average liveweight gain (LWG) for the first two drafts decreased from 106 to 84 g/head respectively (Table 3). The calculated optimum stocking rate using the Jones and Sandland (1974) model (the point at which maximum LWG/ha occurred, based on the first draft lamb performance) was 36 sheep/ha, but decreased to 17 sheep/ha for the second draft (Fig. 3). This response difference between the two drafts suggested that these optimums were unstable and would decrease further as availability of forage lessened under decreasing light transmission. Ultimately the optimum stocking rate was reduced to as low as 2 sheep/ha, as was found in seven-year-old rubber. Based on the average performances of the two drafts of lambs, animal production in immature rubber ranged from 155 to 429 kg/ha/year at the stocking rates of four and 14 sheep/ha respectively (Table 3).

Table 1. Changes in botanical composition (%) with grazing under immature rubber.

	Control	SR-4	SR-6	SR-8	SR-10	SR-12	SR-14
Calogoponium caeruleum							
pre-grazing	42	41	55	32	38	50	42
post-grazing	52	67	97	92	96	100	98
Pueraria phaseoloides							
pre-grazing	7	7	7	1	7	2	6
post-grazing	5	0	0	0	0	0	0
Paspalum conjugatum							
pre-grazing	42	38	21	61	46	44	51
post-grazing	23	12	3	6	2	0	1
Mikania cordata							
pre-grazing	4	6	9	2	4	2	1
post-grazing	12	17	0	0	0	0	0

Table 2. Changes in botanical composition (%) with grazing under mature rubber.

	Control	SR-2	SR-4	SR-6	SR-8
Cyrtococcum oxyphylum					
pre-grazing	29	11	31	14	31
post-grazing	23	17	51	26	64
Paspalum conjugatum					
pre-grazing	17	26	19	13	14
post-grazing	26	9	15	18	9
Calogoponium caeruleum					
pre-grazing	24	17	25	37	12
post-grazing	7	10	12	22	12
Pueraria phaseoloides					
pre-grazing	2	7	5	6	19
post-grazing	2	4	1	3	2
Mikania cordata					
pre-grazing	21	8	7	15	8
post-grazing	6	3	2	4	0
Asystasia intrusa					
pre-grazing	0.1	21	0	3	0.2
post-grazing	24	42	0	5	0
Other species					
pre-grazing	7	10	13	12	16
post-grazing	12	15	19	22	13

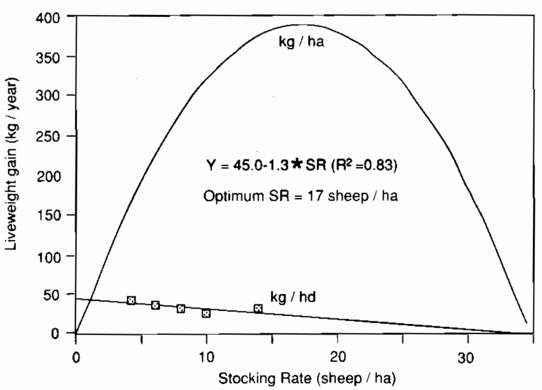

Fig. 3. The relationship of liveweight gain with stocking rate for the second draft of lambs (second six months) under immature rubber.

In the case of mature rubber, the optimum stocking rate was 2–3 sheep/ha for sustained sheep grazing (Table 4). At higher stocking rates, only intermittent grazing and low animal gains were possible. Actual stocking rates (based on grazing days achieved in the various treatments) did not exceed 3.2 sheep/ha (Table 4). Based on SR-2, a maximum animal production of 72 kg/ha/year was achieved.

As the true optimum stocking rate is associated with the optimum utilisation of forage and most economic rate of animal gain/head rather than maximum animal gain per ha, the appropriate stocking rate would be somewhat less than 17 sheep/ha for the three-year immature rubber. However, based on these stocking rates, the animal productivity under rubber may vary from around 387 kg/ha/year in immature rubber to 72 kg/ha/year for mature rubber.

Table 3. Effect of stocking rate on animal production under immature rubber (average of two drafts of lambs).

Stocking rate	Average daily gain (g/head)	Animal production (kg/ha/year)
SR-4	106	155
SR-6	97	212
SR-8	86	251
SR-10	83	303
SR-12	-	-
SR-14	84	429

Conclusions

The results of the concurrent grazing trials carried out under both immature and mature rubber clearly demonstrated the upper and lower limits of sheep production based on the level of forage availability and sustainability. While high stocking rates and good levels of animal productivity could be exploited under immature rubber, very low animal productivity was sustainable under mature rubber.

The early high levels of forage production under immature rubber of about 2200 kg/ha supported a high

Table 4. Effect of stocking rate on animal production under mature rubber (average of three drafts of lambs).

Stocking rate	Range of grazing days achieved	Actual stocking rate (sheep/ha)	Weighted average daily gain (g/head)	Animal production (kg/ha/year)
SR-2	190–196	2	99	72
SR-4	71–104	1.5–2.2	26	38
SR-6	70–96	2.2–2.9	19	42
SR-8	48–79	2.0–3.2	11	32

stocking rate of around 17 sheep/ha with a rather high animal productivity of just under 400 kg/ha/year. However, it was clear that the sustainable stocking rate steadily reduced as forage productivity declined under maturing rubber.

In mature rubber, the forage availability was less than 600 kg/ha and this supported a stocking rate of only 2–3 sheep/ha. At 2 sheep/ha, a very low animal productivity of about 72 kg/ha/year was achieved. The problem of managing sheep under rubber is therefore associated with the need to progressively reduce stocking rate as the rubber matures.

Nevertheless, the objective of sheep integration under rubber is not just to produce meat, but also to control weeds. Significant cost savings will result from the reduction in weeds by grazing sheep. These weeds are normally controlled chemically. However, excessively high stocking rates will lead to the dominance of unpalatable species such as *Calopogonium caeruleum* to the detriment of animal production, especially in immature rubber. It is suggested that this species should not be sown in plantations designated for grazing by sheep. New species are required which are shade-tolerant and persistent, yet palatable in the declining light environment of rubber plantations.

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Supplementation of Sheep under Rubber in Indonesia

M.D. Sanchez*

Abstract

Feed supplementation, either continuous or strategic, increased litter size, weight of the litter at weaning and reduced lambing interval. Supplementation also increased lamb growth rates and improved the efficiency of feed utilisation. However, supplementary feeding is not always economically feasible. Some important constraints to the integration of sheep with rubber plantations are discussed.

THE integration of sheep into rubber plantations has been practised since the mid-1970s in Malaysia (Ani et al. 1985) with a rapid expansion of commercial production by both private and government-supported programs. However, the research component, essential to the success of the enterprise, has not kept up with the demands of this growing activity. In Indonesia, the concept of integration of sheep into rubber plantations has not left the research station. There are only scattered small flocks around the edges of the plantations with primitive or non-existent management systems. Large plantation companies still prohibit grazing or harvesting of forage under the trees, a regulation that appears more related to keeping people off the plantations than to the actual damage that those activities might cause directly to trees.

This paper reviews part of the research conducted on the animal component of the integration of sheep into the rubber plantations by institutions under the umbrella of the Agency for Agricultural Research and Development of Indonesia, in conjunction with the USAID Small Ruminant Collaborative Research Support Program (SR-CRSP) at Sei Putih, North Sumatra, since 1985.

Sheep Breeds

Among the components that determine the productivity of sheep, one of the most important is the breed. In Indonesia, there are three major breeds of sheep: the Javanese Fat Tailed (JFT), concentrated in the eastern part of Java and neighbouring islands, which is used in free grazing and in cut-and-carry systems associated with plantations (e.g. coffee); the Javanese Thin Tailed (JTT), including the Garut fighting sheep, from the western part of Java, used predominantly in cut-and-carry systems in areas of intensive agriculture and dense population; and the Sumatran Thin Tailed (STT) of the island of Sumatra, which is grazed around plantations and agricultural areas. Recently the SR-CRSP introduced the White Saint Croix sheep, a hair-type sheep, in an attempt to increase the rate of gain and size of local sheep. A hair type was chosen in order to improve coat characteristics and therefore sheep adaptation and productivity in these hot and humid conditions.

Management of Sheep

The results presented here were obtained with STT sheep and crosses with the St Croix sheep, the two main breeds so far utilised at Sei Putih. The management system involves either free or rotational grazing during the day (0800 to 1600 hours) on the native forage under rubber plantations. The main species consumed are the grasses *Paspalum conjugatum*, *Ottochloa nodosa*, *Cyrtococcum oxyphylum*, the legumes *Pueraria phaseoloides* and *Centrosema pubescens*, the forb *Mikania cordata* and the leaves, fallen or from spontaneous plantules, of the main crop *Hevea brasilensis*. After grazing, the animals return to traditional wooden barns with elevated slat floors, where most management takes place, including supplementary feeding, mating, lambing and weighing.

Post-lambing ewes and lambs stay indoors for a period of about two weeks, or until the lambs are strong enough to keep up with flock, and are fed cut forage from the plantations or from the introduced forage plots. Most animals receive feed supplementation according to the research protocols,

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either in individual stanchions or by group, usually after grazing. Salt and mineral blocks are available in the pens. Water is provided outside the barn and sheep have access to it before and after grazing. Two systems of mating are used. One flock (STT ewes only) is in a continuous mating system with rams mixed with ewes only in the barn. Another group (STT and St Croix crosses) is in a seasonal mating system, with four breeding times each year. Internal parasite control is performed approximately every four months on the whole flock, with extra drenching for the ewes at lambing and for the lambs at weaning time. Various commercial anthelmintics are utilised alternately.

Productivity of ewes under continuous supplementation

A flock of STT sheep was acquired from surrounding villages and for the first three years ewes were divided into four groups receiving one of four daily levels of energy supplementation (0, 0.6, 1.0 or 1.4% of bodyweight) provided by concentrates made of a mixture of rice bran, cassava meal, molasses, fish meal, urea and limestone (Reese 1988). A constant level of protein was maintained. Ewes were kept in a continuous mating system and semi-rotational day grazing in an 18-year-old rubber plantation (Clone Avros 2037), with an initial stocking rate of 6.7 ewes/ha.

Table 1 presents a summary of results from this experiment. As can be observed, energy supplementation progressively improved the overall productivity of the ewes, both per head and per weight of the ewe. This was achieved by means of increasing litter size and weight of the litter at weaning, while reducing lambing interval. Weight of the ewes postpartum, and possibly body condition, was also ameliorated with supplementation. The increases in litter size in STT ewes are possible due to the existence of a major gene that controls prolificacy (Bradford et al. 1986). In the absence of the gene, ewes will produce one and occasionally two lambs. But in its presence, the number of lambs will be determined in part by the nutritional status. In general, large litter sizes are related to higher ewe productivity.

Although Reese (1988) initially reported that the highest level of supplementation gave good economic returns, a more detailed analysis (Sanchez et al. 1989) revealed that none of the supplementation levels provided economic gains as high as the non-supplemented group. The expensive ingredients used and the fact that feed was provided daily, regardless of the nutrient requirements, contributed to this outcome.

Productivity of ewes on strategic supplementation

An alternative way to reduce the amount of supplementary feed is to give it when the ewes need it most, in periods of high nutrient requirements. To study this strategic supplementation, a flock of STT and F1 STT × St Croix (SC) ewes bred to SC rams was used. The mating system was seasonal, four times per year, and the grazing was with a shepherd. A mixed supplement was given to ewes for the last six weeks of pregnancy and during the three-month lactation.

The results of this work are summarised in Table 2. Litter size was slighly increased with supplementation, but there were significant increases in the weight of lambs weaned per lambing and a reduction in the parturition interval. The combination of these effects resulted in increased productivity per ewe (+ 36%) and per weight of ewe (+ 20%) in the supplemented animals compared with the control animals on grazing only. Supplementation reduced the average lambing interval by raising the proportion of ewes lambing approximately every six months from 56 to 76% in STT ewes and from 45 to 68% in F1 STT × SC ewes. Milk production and milk fat were increased by supplementation (Sanchez et al. 1990) which contributed to higher lamb weaning weights.

Supplementation of lambs

An essential component of sheep production systems oriented to rapid marketing is rearing of lambs after weaning. The purpose of these growing trials with lambs was to search for supplementation methods that

Table 1. Productivity of Sumatran Thin Tailed ewes with increasing levels of feed supplementation. After Reese (1988).

Feed level (% BW)	Litter size	Lamb weight per lambing (kg)	Lambing interval (days)	Yearly lamb weight (kg)	
				per ewe	per kg ewe
0	1.32^{a}	11.1^{ab}	219^{a}	19.0^{a}	0.92^{ab}
0.6	1.37^{a}	9.8^{a}	198^{b}	18.2^{a}	0.83^{a}
1.0	1.42^{a}	12.5^{b}	194^{b}	23.6^{b}	1.01^{bc}
1.4	1.83^{b}	13.2^{b}	193^{b}	25.1^{b}	1.13^{c}

Values within columns with different superscripts are significantly different ($P < 0.05$).

Table 2. Productivity of ewes on strategic supplementation.

Treatment	Ewe breed	Lamb breed	Litter size	Lamb weight per lambing (kg)	Lambing interval (d)	Yearly lamb weight per ewe (kg)	per ewe (kg)
Control	STT[1]	F1[2]	1.20	9.5	250	14.3	0.68
	F1	BC[3]	1.35	10.0	232	16.9	0.65
Supplemented	STT	F1	1.41	9.7	213	16.9	0.76
	F1	BC	1.37	14.5	223	24.1	0.84
Probabilities							
treatment			ns	0.001	0.05	0.001	0.05
genotype			ns	0.001	ns	0.001	ns

[1] Sumatran Thin Tailed Sheep
[2] F1 cross of Sumatran Thin Tailed with Saint Croix sheep
[3] Back cross (75%) to Saint Croix sheep.

would allow rapid rates of gain during growth and fattening phases, when animals had plantation forage as the main component of their diets. For this work, lambs produced in the ewe flock were used, including STT, F1 STT × SC and back crosses (BC) with SC. Lambs were grazed during the day under rubber plantations with a shepherd and were fed individually the various concentrates in the barn. Only molasses supplementation was given on a group basis. These growing trials lasted 90–120 days.

Table 3 contains a summary of these growing trials, including the type of supplement, feeding levels, breed of lamb and average daily gains (ADG). Results obtained in the first trial (Sanchez and Boer 1989) indicated that a supplementation level of about 0.6% of body weight (BW) per day was adequate for an efficient utilisation in both STT and F1 lambs. In most of the subsequent trials this level was used. There was no advantage in adding fish meal (bypass protein) or broken rice (bypass energy) to palm kernel cake (Boer and Sanchez 1989). Neither was it beneficial to include bypass protein at various levels in cassava meal–molasses supplements (Sanchez and Pond, pers. comm.). The form of the extra energy, either soluble (molasses) or slowly degraded, partly bypass (broken rice) or their combination, did not give a different growth response (Sanchez and Pond 1989a).

Afternoon feeding of the concentrate produced an ADG which was 12% higher than morning feeding but this was not statistically significant (Sanchez and Pond 1989b). PKC supplementation allowed 40% higher ADG in lambs rotationally grazing at six and 12 head/ha (Sanchez et al. 1990). In general, supplementation produced increases from 27 to 65% in the ADG of lambs, with an average of 40%. Although the data are not included in this review, supplementation increased the efficiency of feed utilisation and in most cases gave economic returns.

Some Current Limitations of Sheep Productivity

The STT sheep have given excellent levels of production under these systems of grazing in rubber plantations, comparable with or superior to those of the improved temperate breeds (Iniguez et al. 1990). However, some current limitations are:

(1) high mortality of lambs with low birth weights, caused by small size ewes at lambing and by large litters. Larger size should be attained before the first mating in order for the ewes to reach at least 80% of their adult body weight by first lambing. Ewes that consistently produce large litters (three or more lambs) should be selected against in these grazing systems;

(2) low weaning weights caused by insufficient milk. Selection, cross-breeding or supplementary feeding of the STT ewes is required to increase milk production to make it adequate for the litter size;

(3) the presence of internal parasite larvae in the pastures, in particular, *Haemonchus*, *Oesophagostomum* and *Eurytrema*, the pancreatic fluke. Effective methods of management combined with medication are required to reduce the deleterious effect of these parasites on the health and productivity of sheep;

(4) on the forage side, there is a mismatch between the increasing flock size in new operations and the continuous reduction of forage in new plantations. In already established plantations, with regular cycles of replanting schemes, projections of flock size can be made more easily;

(5) in progressive plantations there will be a reduction of forage available for sheep with the appearance of new, more productive, fast-growing clones. There is a need for specific effort in increasing forage growth by the use of special planting designs; and

Table 3. Average daily gain of Sumatran Thin Tailed and crossbred lambs when grazing with and without feed supplements.

Supplement	Feeding level (% BW)[1]	Average daily gain (g) STT[2]	F1[3]	BC[4]
None	0	47[a]	68[a]	—
Mixed concentrate[5]	0.6	75[b]	85[b]	—
Mixed concentrate	1.2	80[b]	93[b]	—
None	0	63[a]	—	—
Palm kernel cake (PKC)	0.6	97[b]	—	—
PKC + 10% fish meal (FM)	0.6	93[b]	—	—
PKC + 10% broken rice (BR)	0.6	103[b]	—	—
PKC + 10% FM + 10% BR	0.6	83[b]	—	—
Cassava meal/molasses (80:20)	0.6	72[a]	100[a]	120[a]
+ 10% fish meal	0.6	54[a]	104[a]	89[a]
+ 20% fish meal	0.6	60[a]	122[a]	81[a]
+ 30% fish meal	0.6	52[a]	132[a]	119[a]
None	0	45[a]	48[a]	—
Molasses	1.3	61[a]	54[a]	—
Broken rice	1.0	54[a]	59[a]	—
Molasses + 43% broken rice	1.2	56[a]	61[a]	—
Palm kernel cake				
morning	0.6	47[a]	68[a]	—
afternoon	0.6	53[a]	76[a]	—
None				
6 sheep/ha	0	—	—	80[a]
12 sheep/ha	0	—	—	83[a]
Palm kernel cake	0	—	—	—
6 Sheep/ha	0.6	—	—	117[b]
12 sheep/ha	0.6	—	—	112[b]

1 Per cent body weight
2 Sumatran Thin Tailed
3 F1 cross between Sumatran Thin Tailed and Saint Croix sheep
4 Back cross (75%) to Saint Croix
5 Made from PKC 38.6%, rice bran 38.6%, molasses 20%, fish meal 1.5% and limestone 1.3%.
Values within columns with different superscripts are significantly different ($p<0.01$).

(6) the presence of the noxious weed *Imperata cylindrica* in rubber plantations not only competes with the trees for water and nutrients, but also replaces desirable forage species. Sheep do not voluntarily consume *Imperata*, so other special methods of control are still required.

Other Constraints

Apart from the limitations mentioned above there are some other constraints on the successful integration of sheep into the rubber plantations in Indonesia. These are:

(1) prevalent prohibition of grazing animals or the taking of forage from plantations. A clear distinction should be made between the arguable potential effects of animals on the plantation, from the real damage caused by the behaviour of people associated with the animals. In any case, uncontrolled presence of either of the two, animals or people, should not be permitted. However, a well organised system can be beneficial for all;

(2) the traditional cover crops are of low productivity and generally unpalatable for sheep, and thus cannot be used for purposes of integration. There is a need for more productive and palatable cover crops that can also be accepted by the plantation managers;

(3) the presence of plastic, bags in particular, thrown away by plantation workers, that are consumed by sheep in flocks and cause harmful effects. Often this plastic cannot be regurgitated and remains in the rumen, taking useful feed space and disrupting and blocking normal digestive processes;

(4) the high cost of traditional barns increases the capital required for starting a sheep operation.

Cheaper and movable barn designs should be designed and tested, in particular in relation to increased parasite larvae exposure, microclimate (humidity, temperature, air circulation) and security;

(5) animal theft; and

(6) predation by feral, vicious or underfed loose dogs.

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Compatibility of Forages and Livestock with Plantation Crops

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Abstract

There is an inherent complementarity between plantation crops and the raising of ruminant livestock. The integration of ruminants into plantation crops is most successful when both improved management of the crop and an additional income are possible. Factors affecting the competitive effects of forages on plantation crops are species of forage used, application of fertilizer, and the recycling of nutrients by grazing.

Ruminants may damage plantation crops by grazing foliage and fruit and must be excluded from very young plantations. Bark damage may occur in older dicotyledonous plantations. Goats are especially damaging in this regard but sheep and cattle may also damage the trunks of trees. One major advantage of integration is improved control of weeds and reduced use of toxic herbicides.

RUMINANTS have always been associated with plantation crops, both as 'sweepers' for weed control and for animal production. A large variety of crop–livestock combinations has been reported (Table 1); this indicates the inherent complementarity of plantation crops and livestock that can be exploited to improve land use and increase income. The main plantation crops that have been integrated with livestock include coconut, various forestry and horticultural species, and, more recently, rubber and oil palm. All the major domestic ruminant species (cattle, sheep and goats) have been integrated.

Successful integration of plantation crops and ruminants usually requires that the grazing livestock can be used as an aid in the management of the plantation crop, and that the combined income of the two enterprises is greater than obtained from the plantation crop alone. Moreover, as the plantation crop is usually, but not always, the main economic activity, any substantial negative effects of the livestock on either the yield or the management of the plantation will render the combination incompatible.

This review will discuss the compatibility of various plantation crop–livestock combinations concentrating on coconut, rubber and oil palm, although other crops will be mentioned. Compatibility of both forages and ruminant species with plantation crops will be mentioned considering both competitive and synergistic effects.

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Effects of Forages on Plantation Crops

Forages will clearly compete with plantation crops for moisture and nutrients. In situations where rainfall is high and well distributed, and where soil fertility is high or fertilizer is liberally applied, there will be little competition. In practice, such situations rarely exist and competition will occur at various times during the development of the crop.

The effect of such competition from improved forages has to be considered against that from naturally occurring vegetation which is inevitably present. Plantation crops do not fully utilise all incoming radiation, or all of the available moisture and nutrients, and managers must direct both financial and labour resources to the chemical or mechanical control of weeds. One of the positive effects of integration is therefore the 'replacement' of non-productive weed species with productive forage.

Table 1. Examples of ruminant–plantation crop combinations.

Plantation crop	Animal type				
	Cattle	Dairy	Sheep	Goat	References
Coconuts	x	x	x	x	1, 6
Rubber			x		2
Oil palm	x		x		3, 7
Forestry	x				4
Durian			x		5
Mango		x			6

1. Reynolds 1988. 2. Jusoff 1989. 3. Chen et al. 1978. 4. Shelton et al. 1987. 5. Najib 1990. 6. Moog (pers. comm.). 7. Tajuddin (pers. comm.). 8. Sophanodora (pers. comm.).

Forages in plantations which achieve closed canopy

In rubber and oil palm, and many forest plantations, competition with understorey vegetation occurs only during the immature phase before canopy closure. At this point light transmission is low (often <20%) and competition is minimal. However, during the immature phase, the developing trees are susceptible to weed competition and twining leguminous cover crops are usually planted to control less desirable weeds, especially in rubber and oil palm.

Cover crops are used to both 'smother' undesirable weed growth and to contribute to early rubber growth through nitrogen accretion (Watson 1963). Broughton (1977) in a survey of the effect of various covers on soil fertility and growth of rubber concluded that growth rate, trunk girth, tree height, bark renewal and ultimately latex yield is enhanced by the presence of the leguminous covers. Broughton further suggested that the effect may be smaller on fertile soils and can be partially offset on infertile soils by the application of higher rates of fertilizer. An example of this is shown in Table 2 of Pushparajah and Mahmud (1977). Latex yields were substantially lower when grown with improved grasses or with natural vegetation than when grown with leguminous cover crops. However, there was some recovery of yield when high rates of nitrogen fertilizer were applied.

Table 2. Effect of nitrogen fertilizer on accumulative latex yield over 14 years.

N treatment	Cover crop (kg/ha)	Grasses only (kg/ha)	Natural vegetation (kg/ha)
Low N	19 620	16 820	18 390
High N	20 620	20 670	20 460

Source: Pushparajah and Mahmud 1977.

The introduction of high-yielding grasses into young rubber plantations may be expected to exert a stronger competitive effect than either leguminous cover or natural vegetation, primarily due to the increased demand for nitrogen. This is of concern as a limitation to the growth of young rubber will adversely effect the yield potential of mature rubber (Broughton 1977).

Waidyanatha et al. (1984) investigated the effects of the grasses *Panicum maximum*, *Brachiaria brizantha* and *B. miliiformis* grown in monoculture with moderate applications of nitrogen fertilizer or in association with *Centrosema pubescens* and *Pueraria phaseoloides*, on girth increments in young rubber. Increments were significantly lower in rubber growing with grass monocultures and with mixtures (which contained little legume) than with the leguminous cover crop control. The effect was apparent for the first three years but not thereafter. In this experiment, *B. miliiformis* was less competitive but there was no clear relationship between pasture yield and girth increments of the trees.

In another experiment, Dissanayake and Waidyanatha (1987) compared the effects of various regularly cut grasses which were moderately fertilised (100kg N/ha), with a *Pueraria phaseoloides* cover crop on growth of young rubber over a 2.5-year period. The grasses varied in their effect and some were actually less competitive than the cover crop (Table 3). As in the previous experiment there was no significant correlation between forage yield and tree girth or tree height. In a second experiment by the same authors, a different result was obtained as tree girth was larger when grown with *Pueraria phaseoloides* (9.5 cm) than when grown with either *Panicum maximum* (7.9 cm) or *Brachiaria ruziziensis* (8.3 cm). The effects of grasses on rubber yields are therefore not definitive.

In these experiments, grasses were cut and removed, resulting in substantial removal of plant nutrients. For instance, the average removal of dry matter over the period of the experiment was 18.3 t/ha. Assuming a concentration of 1.4% N, then 256 kg/ha of nitrogen was removed while only 100 kg/ha was added.

In grazed pastures, however, most of the ingested nitrogen is returned to the soil as excreted dung and urine. Unfortunately there is little data on the effect of grazing leguminous covers or natural vegetation on the growth of young trees. Kamaruzaman Jusoff (1989) reported higher soil and rubber leaf N and P levels in grazed than in ungrazed plots of young rubber. Tree girths were also larger in grazed than in ungrazed plots but variability was too high to make definitive conclusions. In another study, the N and K concentrations in durian leaves were increased after a period of grazing of understorey herbage by sheep (Mohd. Najib 1990).

Table 3. Girth of 2.5-year-old rubber trees grown in association with various forage species.

Species	Tree girth* (cm)
Panicum maximum (cv. Petrie)	9.6^{a}
Setaria sphacelata (cv. Kazungula)	9.3^{a}
Paspalum plicatulum	9.0^{ab}
Brachiaria miliiformis	8.9^{abc}
Brachiaria ruziziensis	8.5^{bcd}
Pueraria phaseoloides (Control)	8.2^{cd}
Panicum maximum (A)	7.8^{de}
Panicum maximum (B)	7.2^{e}
Brachiaria decumbens	7.1^{e}
Pennisetum purpureum (NB21)	7.1^{e}
Brachiaria brizantha	5.7^{f}

*Girths followed by different superscripts are significantly different ($P < 0.05$).
Source: Dissanayake and Waidyanatha 1987.

Forages in open canopy plantations

The situation is different under plantations with open canopies such as coconuts. Here light transmission remains high for the life of the crop, as the majority of coconut plantations are of the tall, well spaced varieties. There are many reports on the effects of understorey forages on coconut yield and these have been reviewed by Reynolds (1988). These have variously shown positive, negative or nil effects on coconut yield. A summary of some of the important results is given below.

Application of fertilizer can reduce the competitive effects of understorey vegetation. Reynolds (1988) in his review showed that the negative effect of high-yielding grasses can be ameliorated and sometimes switched to a positive effect by appropriate fertilisation.

The presence or absence of grazing animals is important. Grazing of natural vegetation under coconuts in East Africa nearly doubled yield compared to ungrazed areas (Childs and Groom 1964). Such effects can be attributed partly to improved nut collection but also to the recycling of nutrients 'locked up' in the standing biomass, as previously discussed. Santhirasegaram (1966) showed that coconut yield was reduced by 28% in a lightly fertilised but ungrazed *Brachiaria brizantha* pasture compared to ungrazed natural vegetation. When the *B. brizantha* pasture was grazed, the reduction was only 13%.

Variation in grazing system or stocking rate usually has only a small effect on coconut yield (Reynolds 1988). An exception is the data of Rika et al. (1981) who found that the yield of coconuts was higher at higher stocking rates (Table 4). This may have been related to the greater utilisation of forage and therefore improved nutrient cycling. Fertilizer (20 kg P/ha) was applied at planting only, and none was applied directly to the coconuts. Palms therefore relied on fixation and accretion from the legume component of the pasture for nitrogen.

Forage species vary in their competitiveness with coconuts (Reynolds 1988). In one experiment, coconut yield was substantially lower in moderately fertilised *Brachiaria mutica* and *Panicum maximum* pastures than in unfertilised natural pastures (Table 5) (Reynolds 1981).

Table 4. Effect of stocking rate on coconut yield in Bali.

Pasture treatment	Stocking rate (cattle/ha)	Coconut yield* (nuts/ha/month)
Natural pasture	–	291
Sown pasture	2.7	263[a]
	3.6	287[a]
	4.8	439[b]
	6.3	454[b]

*Yields followed by different superscripts are significantly different ($P < 0.05$).
Source: Rika et al. 1981.

Competition for moisture may also reduce coconut yield as coconuts are sensitive to moisture stress (Smith 1966) which causes abortion of young inflorescences (Chile 1974 cited in Reynolds 1988). In areas with a pronounced dry season, drought-tolerant grasses may further reduce moisture supply to palms and decrease nut yield. As *Brachiaria miliiformis* tends to cease growing at the onset of moisture deficit, it is regarded as being less competitive than some other species (Lane 1981 cited in Reynolds 1988).

Physical structure of forage plants is also important in coconut plantations. Tall species such as some cultivars of *Panicum maximum* make location of coconuts difficult and increase the labour requirements during the coconut harvest. Shorter, decumbent or stoloniferous types are preferred in this regard.

Table 5. Effect of various grass species on coconut yield over a 1-year period.

Species	Coconut yield as % of that obtained on natural pasture*
Natural pasture	100[a]
Ischaemum aristatum	86[c]
Brachiaria brizantha	102[a]
Brachiaria miliiformis	92[b]
Brachiaria mutica	70[e]
Panicum maximum	79[d]

* Yields followed by different superscripts are significantly different ($P < 0.05$).
Source: Reynolds 1981.

Direct Effects of Ruminants on Plantation Crops

The compatibility of various ruminant species for grazing under plantation crops varies. An understanding of this compatibility has evolved largely on a 'trial and error' basis. Incompatibility is based on unacceptable damage or interference in the management of the plantation crop.

In all plantation types, animals are kept away from young trees until fronds or leaves are out of reach of the grazers. Both cattle (Chen et al. 1978) and sheep (Pillai et al. 1985) have been reported to browse fronds and nibble the bunches of oil palm. However, the authors concluded that damage was minor with only a negligible effect on yield. Pillai et al. (1985) suggested that damage was greater when forage resources under the palms were depleted.

Goats are renowned for their browsing of both tree foliage and bark. Bark damage sometimes occurs with species other than goats. Sheep damage to the bark of young rubber has been observed at the Malaysian Rubber Research Institute experimental station at Sg. Buloh (Tajuddin I., pers. comm.) but was relatively minor in the study of Pillai et al. (1985). Rams in particular cause damage when sharpening their horns.

Cattle grazing under *Eucalyptus deglupta* and other forestry plantations in the Solomon Islands caused serious damage to trees (Shelton et al. 1987). Damage to the trunk took two forms; bark stripping caused by cattle feeding on the bark was the most serious, but damage to the outer sapwood layer caused by cattle rubbing against trees also occurred. Damage to bark resulted in a doubling of the incidence of entry of decay fungi into the lower trunks of trees. Damage to the exposed main surface roots was also suspected but not confirmed.

Direct damage to stems of mature oil palm or coconut is minimal although there are concerns over possible soil compaction (Chen et al. 1978) and increased erosion hazard that may occur at higher stocking rates. Rubber root damage has been observed at the Rubber Research Institute of Malaysia from the treading effects of grazing cattle (Tajuddin I., pers. comm.). Cattle and goat are incompatible in rubber as they disturb the tapping cups.

There are also some negative effects of plantation crops on the grazing animal. Sheep have been observed to suffer from an abnormally high proportion of cuts (up to 24% in one case) when grazing oil palm due to the sharp spines on the petioles of fallen fronds (Tajuddin I., pers. comm.). This effect can be minimised by careful movement of the flock through the plantation or 'heaping' of the fronds.

On the positive side, apart from the recycling of nutrients, grazing ruminants are important in weed control in all plantation crops. Early this century, the principal reason for the grazing cattle in estate coconut plantations in the South Pacific was brush control. Currently, in Malaysia, it is estimated that the grazing of sheep in young rubber plantations results in a saving of approximately 30% of the costs of chemical weed control (Tajuddin et al. 1990). These savings, together with the reduced chemical hazard of ruminant grazers compared to chemical control, are important factors in the promotion of sheep grazing under plantation crops in Malaysia.

Conclusions

The integration of ruminants into plantation crops is most likely to be successful where both improved management of the crop as well as an additional income is feasible. It is imperative that the introduction of forages and grazing animals into plantations does not substantially interfere with management or reduce the yield of the plantation crop.

There are a number of factors which appear to influence the level of competition. Legumes are less competitive than grasses; there is variation among the species of grasses in their competitiveness; application of fertilizers reduces competition; and grazing promotes the recycling of nutrients so that yield of the plantation crop may even be improved.

Ruminants will graze foliage and fruit in very young plantations and must be excluded at this stage. Bark damage may occur in older dicotyledonous plantations. Goats are well known to cause this problem but cattle may also damage the trunks of trees. Soil compaction and root damage have been noted by some authors.

There is scope for greater integration of ruminants into plantation crops because of the inherent complementarity of the two enterprises.

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Compatibility of Grass–legume Swards under Shade

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Abstract

Grass-legume swards form the basis of many productive pasture systems. Tropical pasture species grown under different levels of shade can exhibit both morphological and physiological changes in shoot to root ratio, leaf area ratio, specific leaf area and radiation use efficiency. These changes may affect the compatibility of grass-legume swards when grown in shaded environments.

Pure grass swards were compared to grass-legume swards under three light regimes. The proportion of legume yield was higher under shade than in full sun swards. The canopy extinction coefficient was lower in light shade than in full sun but was similar to full sun in dense shade. Generally, radiation use efficiency increased with shade. The implications of these results are discussed.

THE benefits of integration of pastures with plantations have been well documented (Shelton et al. 1987; Reynolds 1988; Chen 1989). However, few studies have examined the growth and compatibility of species mixtures (grass–legume) under shade. Mixed pasture swards commonly comprise two major plant groups, namely C4 grasses, which are fast-growing species, and C3 legumes, which are slower-growing species. Hence mixtures of grasses and legumes may be incompatible unless the legumes possess other mechanisms to improve their competitive vigour. Three mechanisms of response of species to shade are avoidance, tolerance and obligate shade requirement (Ludlow 1980). Only the latter two response mechanisms would be suitable for pastures under plantations, since the understorey species cannot avoid shade from the taller plantation crops. These strategies require that species are able to maximise radiation use efficiency, leaf area and light interception (Smith 1981).

It is clear that most improved tropical pastures are sun species (Ludlow 1978) with poor adaptation to dense shade. However, tropical pasture species when grown under shade can exhibit both morphological and physiological changes in shoot to root ratios, leaf area ratio, specific leaf area and radiation use efficiency (Sophanodora 1989).

This study was conducted to evaluate the effect of shade on the productivity of two tropical grasses grown in monoculture and the compatibility of mixture with a legume.

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Materials and Methods

Pure grasses swards of guinea (*Panicum maximum*) and signal (*Brachiaria decumbens*) and mixtures with centro (*Centrosema pubescens*) were established on a well-drained, fertile krasnozem soil at Redland Bay Farm, University of Queensland in January 1985. Grass seedlings about three weeks old were transplanted at spacings of 0.20 x 0.25 m into plots 2 x 3 m. For the mixed swards, legumes and grass seedlings were planted alternately along the row to give a 50:50 grass to legume mixture. Ten days after transplanting, structures covered with shade cloth were erected 1.5 m above the plots. The radiation regimes were 30, 70 and 100% of full sunlight. There were four replicates per treatment. Plots were irrigated regularly to avoid periods of water stress, no fertilizer was applied, and weeds were removed.

One month after commencing the shade treatments, all swards were cut to about 6 cm above ground level. This was designated day 0 for calculation of days after treatment (DAT) and at approximately weekly intervals, herbage was harvested from quadrats of 0.4 x 0.5 m at about 5 cm above ground level to determine dry weight and leaf area of the component species. Before each harvest, the percentage of midday photosynethically active radiation (PAR) interception by the canopy was measured by a linear probe (Muchow and Kerven 1977). The relative profile of intercepted PAR was measured in successive strata of 0.20 m depth from ground level.

The accumulated amount of PAR intercepted by the canopy was calculated from the sum of the product of mean relative percentage PAR interception by the canopy during two successive measurements and daily incoming PAR.

Extinction coefficient (K) of canopy was calculated from the equation (Charles-Edwards 1982)

$$K = -(\ln(I/I_0))/LAI$$

Where ln is the natural logarithm, I and I_0 are the light flux density below and above the canopy, and LAI is the leaf area index. The slope of the linear regression between accumulated intercepted PAR and herbage yield was regarded as mean radiation conversion efficiency (E_b) of the canopy.

Results

Herbage yields were markedly affected by shade treatments; the absolute reduction of herbage yield was greater in signal than in guinea (Fig. 1), although signal outyielded guinea. The proportion of legume yield in mixtures increased as level of radiation decreased. This was possibly due to the reduction in growth advantage of the grasses under shade and because legume growth was suppressed at 100% light by the initially strong growth of the grass. The yield of guinea grass in this experiment was lower than would normally be expected.

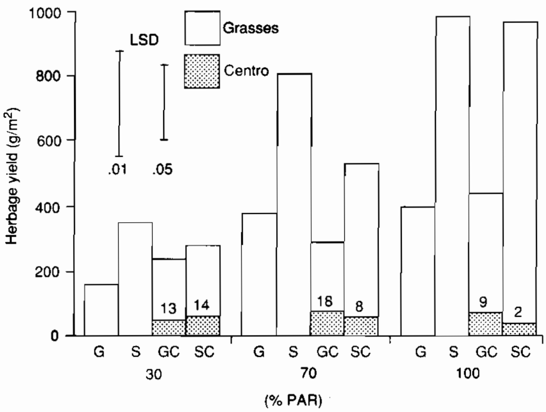

Fig 1. Herbage yield (g/m^2) of pure guinea (G), pure signal (S) and mixture of the grasses with centro swards (GC and SC) at 51 days regrowth under 30, 70 and 100% of full sunlight.

Generally, the lesser proportion of total LAI which occurred in the lowest stratum (0 – 40 cm) was lower at 30% and 70% light than in full sunlight (Table 1). Guinea was taller than signal. The lower stratum also contained less productive leaves due to shading by the upper leaves and the older age of leaves. A lower proportion of LAI in the top stratum suggested a better light penetration through to the lower stratum and hence centro would be able to intercept more radiation, since most centro leaves were in the lower stratum.

K value decreased in light shade (70% light) then increased at 30% light; however, there was not much difference in K value between pure and mixed swards, particularly under shade (Table 2).

Generally, radiation conversion efficiency (E_b) increased under low radiation, and centro swards had a lower E_b than pure grass swards. However, the increase in E_b under dense shade was greater in mixed swards than in pure grass swards. E_b of signal grass was higher than that of guinea grass.

Discussion

There was no growth advantage of the long erect-leaved guinea over the shorter, more prostrate-leaved signal in monoculture. This may have been associated with the low LAI and low solar radiation interception of the guinea grass which did not grow as well as was expected. Shading caused erect plants to lodge more readily.

Herbage productivity can be explained in terms of the amount of intercepted PAR and E_b. The increase in E_b under shade was not sufficiently large to compensate the reduction in amount of intercepted PAR. The percentage increase of E_b under dense shade was less in the pure grass swards than in the mixtures, hence the centro component was increased with shading. It might be expected therefore that centro would compete under conditions of greater equality in shade.

This study did not consider root dry matter, which provides a competitive sink demand for photosynthate and nitrogen. Under shade conditions, root demand

Table 2. Canopy extinction coefficient (K) and radiation conversion efficiency E (g/MJ) and relative increase, compared to full sun (in brackets), of the pure and mixed guinea and signal swards under 30, 70, and 100% of full sunlight.

Swards	Light transmission (%)					
	30		70		100	
	K	E_b	K	E_b	K	E_b
Guinea	0.55	1.47 (175)	0.44	1.21 (144)	0.51	0.84 (100)
Signal	0.52	2.69 (133)	0.32	2.27 (112)	0.41	2.02 (100)
Guinea/centro	0.52	1.61 (185)	0.42	0.95 (109)	0.65	0.87 (100)
Signal/centro	0.52	2.65 (162)	0.40	1.64 (100)	0.48	1.67 (100)

was presumably less and thus leaf nitrogen content was higher, and this possibly helped to maintain leaf photosynthesis, and this together with the decrease in shoot to root ratio would lead to an increase in E_b. Under these conditions it seems that the benefit of nitrogen symbiosis is a less important strategy for promoting compatibility between shaded grass and legume mixtures. The route to maximise productivity of the shaded mixed swards is via maximum light interception and effective light distribution in the canopy, particularly to the lower profile where the legume LAI occurs.

However, grazing or cutting management would insert an interaction effect on the compatibility of grass–legume swards under shade, since cutting or grazing causes change of sward structure and K value. Preferential grazing may also be involved. Watson and Whiteman (1981) found that under coconuts in Solomon Islands signal virtually disappeared under grazing by the second year where centro comprised 14% of the mixture.

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Sheep Grazing Reduces Chemical Weed Control in Rubber

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Abstract

A review of weed control methods in Malaysian rubber estates showed that the complementary use of grazing sheep reduces the overall costs of weed control by between 16 and 36%. Sheep selectively graze grass and some palatable broadleafed species resulting in a desirable purification of the legume *Calopogonium caeruleum* in cover crop mixtures under rubber. The environmental benefits of integration of sheep under rubber are the reduced use of chemical herbicides and less bare ground susceptible to soil erosion.

MALAYSIA has 1.8 million ha of rubber and spends approximately 100 million ringgit per year on herbicides to control weeds. These herbicides are mainly used for circle and strip spraying during the immature period of rubber growth (the first five years) when 24 to 30 spraying rounds are carried out (Chee 1989).

Most of the natural vegetation found in the interrow of rubber plantations is palatable to ruminants. Investigations by Wan Mohamed (1978) showed that many of these plant species were highly nutritious and that they could be utilised to support sheep production. Compared to using herbicides, which need protective measures to minimise contamination, use of sheep is safe for operator and environment. It is also a practical and important method for the expansion of sheep production in Malaysia. This paper reviews the latest weed control practices by involving sheep and chemicals in rubber plantations.

Plant Species

Species that are frequently found in immature and mature rubber are given in Table 1. In immature rubber of 1 – 5 years, most of the species are grazed by sheep except *Imperata cylindrica* and weedy shrubs such as *Chromolaena odoratum*, *Melastoma malabathricum*, *Lantana camara* and *Clidemia hirta*. Among legume species, the sheep graze *Pueraria phaseoloides* and *Centrosema pubescens* but will only feed on the young shoots and leaves of *Calopogonium caeruleum*. In mature rubber areas, sheep feed on most species except the woody shrubs and ferns. Young shoots of the ferns *Nephrolepis biserrata* and *Dicranopteris linearis* are also eaten.

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Weed Control by Sheep

Tan and Abraham (1981) found that there was a reduction in undergrowth cover in grazed treatments over an experimental period of one year (Table 2). The decline in percentage of undergrowth cover in grazing treatments, either rotationally or free range, was twice as much as in the field where no sheep were kept.

In the maintenance of rubber plantations, purification of cover crop legumes is normally achieved by spraying glyphosate and paraquat + diuron herbicides. Ani Arope et al. (1985) found that in immature rubber, where *C. caeruleum* was infested with various mixed weeds, sheep grazing could be used to advantage. The selective grazing habit of sheep mainly for *M. micrantha*, *P. conjugatum* and *O. nodosa* helped to purify the legume and increase the percentage of *C. caeruleum* in the stand. Similar results were also demonstrated by Pillai et al. (1985), as shown in Table 3. The sheep preferred first to graze on grasses, followed by legumes (*P. phaseoloides* and *C. pubescens*) and then broadleafed species. After eight months of grazing, the percentage composition was significantly altered. The composition of *O. nodosa*, *P. conjugatum* and *P. phaseoloides*, which were dominant before grazing, was reduced from 30 to 15%, 15 to 5%, and 15 to 2%, respectively. *C. caeruleum* increased to become dominant after grazing. *A. intrusa* increased from 10 to 25% of herbage available.

Effect of Sheep Grazing on Growth of Rubber

The effect of sheep rearing on the growth of rubber was recorded by Tan and Abraham (1981). They found that the girth increment of trees in fields where undergrowth was grazed by sheep, either in rotational or free range grazing systems, was generally higher

Table 1. Plant species frequently present in the interrow of rubber.

	Age of rubber (years) 1 - 2	3 - 5	6 - 10
Legumes	*Pueraria phaseoloides** *Centrosema pubescens* *Calopogonium caeruleum*	*Pueraria phaseoloides** *Calopogonium caeruleum*	*Calopogonium caeruleum* *Centrosema pubescens**
Grasses	*Paspalum conjugatum** *Axonopus compressus** *Digitaria* spp.* *Ottochloa nodosa* *Imperata cylindrica*	*Paspalum conjugatum** *Ottochloa nodosa** *Axonopus compressus**	*Cyrtococcum spp.* *Centosteca lappacea** *Ottochloa nodosa**
Broadleafed	*Asystasia intrusa** *Mikania micrantha**	*Asystasia intrusa** *Mikania micrantha** *Borreria latifolia**	*Asystasia intrusa** *Mikania micrantha**
Ferns			*Nephrolepis biserrata* *Dicranopteris linearis*
Woody shrubs		*Chromolaena odoratum* *Melastoma malabathricum* *Lantana camara* *Clidemia hirta*	*Chromolaena odoratum* *Lantana camara* *Clidemia hirta* rubber seedlings

* preferred by sheep.

Table 2. Effect of sheep grazing at 8 sheep/ha on percentage cover of undergrowth.

Treatments	Ground cover (%) Pre-treatment	After one year
Rotational grazing	100	38
Free range grazing	100	37
Control (no grazing)	100	70

Source: Tan and Abraham 1981.

than those in the fields where undergrowth was not grazed (Table 4). The differences in the growth of the tree may be attributed to a reduction in weed competition and the manure from sheep.

Damage by Grazing of Sheep on Rubber Trees

Tan and Goh (1988) found that in immature rubber, 3m and more in height, ewes did not chew the brown bark of the trees although rams rubbed their heads and horns on the trunk of trees and caused bark to crack. When these sheep were grazed on rubber trees of 2 m and below, rams were able to stand on their hind legs and devour the whole canopy.

Pillai et al. (1985) also reported damage to rubber trees as given in Table 5. Rams caused severe bark damage with their horns and had a habit of rubbing their bodies against trees.

Weed Control by Chemicals

In the past, manual weeding was practised. However, with the present constraint in labour availability in the plantation sector, there is now no alternative but to use herbicides. The herbicides currently used are given in Table 6. The usage of these herbicides depends on cost effectiveness, weed species present, phytotoxicity to rubber and toxicity to operators.

Economics of Combined Grazing and Chemical Control

Ani Arope et al. (1985) obtained a cost saving and increased effectiveness of weed control in rubber by the use of grazing sheep. They found that the flock could effectively weed 430 ha, consisting of 265 ha of immature rubber of 3–6 years and 165 ha of more than 6-year-old rubber. Using herbicides, the cost for the control of weeds ranged from 48 000 to 54 000 ringgit. Using grazing sheep the cost was brought down to 40 000 ringgit, showing a saving of between 8000 and 14 000 ringgit, or 17–26% of the overall

Table 3. Composition of plant species before and after grazing by sheep in the interrows of immature rubber.

	Composition of vegetation (%)		
	June 1984 before grazing	Feb. 1985 after grazing	Difference (%)
Calopogonium caeruleum	5	40	+35
Asystasia intrusa	10	25	+15
Ottochloa nodosa	30	15	-15
Pueraria phaseoloides	15	2	-13
Paspalum conjugatum	15	5	-10
Other grasses	10	6	-4
Other weeds/legumes	10	7	-3
Centrosema pubescens	3	0	-3
Desmodium ovalifolium	2	0	-2

Source: Pillai et al. 1985.

Table 4. Effect of sheep grazing at 8 sheep/ha on growth of rubber.

	Rubber girth measurement (cm)		
Grazing treatments	Pre-treatment	After one year	Growth increment
Rotational	14.1	21.6	7.5
Free range	14.1	22.1	8.0
Control (no grazing)	14.0	20.0	6.0

Source: Tan and Abraham 1981.

Table 5. Effect of sheep grazing at 7.5 sheep/ha on damage of 1.5-year-old rubber trees.

Degree of damage	Proportion of rubber trees (%)	
	Local sheep	Wiltshire crossbreds
Slight	4	19
Severe	1	1
Body rubbing	8	5
Total	13	25

Source: Pillai et al. 1985.

cost of weeding. This was further confirmed by Abdul Karim (1990) who found that sheep grazing in rubber schemes resulted in a drastic reduction in weeding cost. In most cases, only occasional spraying of herbicides was necessary and this was limited to spot spraying of unpalatable weeds. A saving of 30% was achievable in immature rubber 2–4 years old. Tajuddin et al. (1990) found that there was a saving of 18–36% on chemical weed control when sheep were grazed in immature and mature rubber. These variations in level of savings in weed control cost depend on grazing management, stocking rate and age of rubber.

Table 6. Herbicides used for general weed control in rubber.

Herbicides	Mixtures
Paraquat	Paraquat + 2,4-D amine Paraquat + diuron
Monosodium acid Methanearsonate	MSMA + 2,4-D amine + $NaClO_3$ MSMA + diuron
Glufosinate ammonium	GA + 2, 4-D amine GA + DSMA + diuron + 2,4-D amine
Glyphosate	Glyphosate + dicamba Glyphosate + picloram Glyphosate + fluroxypyr Glyphosate + metsulfuron methyl

Weed control using herbicides is most expensive for circle, strip and interrow spraying during the five-year immature period of rubber. Chee and Goh (unpublished data) found that the cost of chemical weed control during the first five years of rubber growth was 1484 ringgit/ha. During that time 23 spraying rounds were made along the planting strips and 15 spraying rounds in the interrows.

Discussion and Conclusion

Results show that using sheep to graze the weeds in rubber will save 16–38% of the total weeding cost. The integration of sheep with rubber will both reduce the amount of imported herbicides for weed control and the chemical pollution of the environment. Integrating sheep with rubber will also increase the returns per unit of farming land. Another beneficial effect of grazing sheep, as compared to herbicides, is that they do not completely kill the weeds and expose land to soil erosion.

Some noxious weeds such as *A. intrusa* and *M. micrantha* are easily controlled by sheep while frequent spraying of herbicides would be required to control them. In immature rubber, the selective grazing habit of sheep of species such as *P. conjugatum*, *M. micrantha* and *A. intrusa* will lead to a purification of *C. caeruleum*. The management of sheep to control weeds needs further refinement and needs to be made complementary to the standard management practices in rubber plantations.

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Methodologies for Fitting New Technology into Productive and Sustainable Pasture Systems

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Abstract

Conventional methods of agricultural research, largely developed in countries with long-term experience in particular crops and pastures, have limitations in the research and development of industries in regions or environments where there is no such experience. The establishment of a beef industry on acid infertile soils in the humid tropics of Queensland is an example. The establishment of ruminant industries under plantation crops is likely to be another. In the Queensland example, conventional research programs were able fairly quickly to isolate a range of pasture plants which would grow on infertile soils when mineral deficiencies were corrected. However, because there was no viable farming system in operation, researchers themselves were uncertain how the results of the experiments were likely to contribute to productivity or sustainability, let alone profitability of the farming enterprises.

A number of methodologies were used to study the integration of new or alternative technologies into farm management systems. Physical and computer-modelling activities were useful for estimating the productivity, sustainability and profitability of alternative systems. Farm survey and monitoring activities were useful for gathering information, increasing understanding and validating research. Application of the various methodologies can be cyclical. Conventional experimentation on farms establishes close contacts between researchers and farmers and in doing so enhances the quality of the information for industry appraisal. Data from the experiments are the building blocks for computer models. Knowledge gaps and sensitive areas, isolated by models, in turn lead to follow up conventional experiments which in turn lead to better computer models to aid farm decision-making.

AGRICULTURAL research is conventionally based on disciplines (e.g. soil science, plant physiology, animal reproduction) and applied to commodities (e.g. rice, rubber, sugar, beef). This has worked well where there has been a long history of a particular agricultural activity. However, problems have arisen with this conventional approach in the following situations: (a) the development of an industry in a region where there has been no long history of that industry; (b) the extension of an industry to marginal land classes or to land classes previously judged to be unsuitable; and (c) multi-enterprise farming situations.

Situations (a) and (c) apply to attempts to develop ruminant industries under plantation crops and all three situations applied to the establishment of a beef industry in the humid tropics of Queensland. This paper describes the stages and methodologies used in research for the development of pasture systems for that industry. Similar methodologies may be appropriate for the research and development of productive and sustainable pasture systems under plantation crops.

The first step was to survey the industry and its resources. The primary aim was to isolate major problems and to consider means of improvement. Industry assessment was followed by conventional research into problems and processes. The next stage was fitting the results of the problem and process research into alternative management packages. This in turn was followed by research and development programs aimed at the selection of optimum bio-economic management systems for particular conditions. As indicated by the title, this paper focuses on the last two stages, but brief descriptions of the industry survey and the problem and process research are given.

Industry Survey

The objective was to gain an understanding of the regional environment and the physical resources used by the industry and then to consider economic aspects. Available climatic data were assembled. Soils and natural vegetation were surveyed, as were representative farm types on the range of land classes.

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Information on land suitability and soil fertility status was given high priority. Farmer experience with plant and animal production was recorded. Markets and other economic issues were discussed with farmers and subject matter specialists.

Much of the environmental and physical information came from government records and mapping agencies, as did a good deal of the economic data. Formal surveys of farmers were not particularly successful. Close contact was initially developed with a few selected farmers who were willing to supply detailed information. These activities resulted in the isolation of a few priority areas for research and the establishment of a number of on-farm experiments on the range of land classes used by the industry. This involved close contact with many farmers and provided information which was of higher quality than that derived from the formal surveys. The benefits of on-farm experiments are outlined by Miller and Lascano (in press).

In the early stages of industry establishment, those problems which should be accorded high priority were readily apparent. However, when the most obvious problems were solved and the industry progressed, a wider range of problems and opportunities for improvement was presented. The setting of priorities for research therefore became more complex and bio-economic modelling was a useful tool for managing this complexity.

Problem and Process Research

This involved the application of rigorous experimental method to carefully formulated questions. The first step was usually the formulation of a null hypothesis and the final step before interpretation was statistical analysis of data. Useful guides to methodologies used in tropical pasture research include Shaw and Bryan (1976), Mannetje (1978) and Clements and Cameron (1980).

In the example of the humid tropics of Queensland, the major problems were unreliable establishment of the recommended species and then poor persistence of those species on the large tracts of acid infertile soils. Two approaches were given priority. The first was to introduce and evaluate new pasture plants with the potential to give sustainable and profitable beef production on the soils of the region (Harding 1972). The second was to study the fertility of the soils to determine if they could be economically modified to satisfactorily sustain growth and productivity of the pasture species already in commercial use (Teitzel 1979).

Both approaches involved laboratory and plant-house studies followed by small plot field experiments and then larger field studies. The larger plots were usually grazed at some stage. Most fertility data were obtained from soil and plant chemistry measurements and from plant yields.

The next stage of conventional pasture experimentation usually involved grazing trials. These normally consisted of a number of pastures studied over at least three fixed stocking rates. Such experiments were costly and have been criticised for giving a poor representation of actual farming systems.

Management Systems Research

The results from the above examples of conventional research into new species introduction and evaluation (Harding 1972) and soil fertility assessment (Teitzel 1979) were exciting. Some treatments were over ten times more productive than control treatments. The results of these experiments were assembled into what were considered to be appropriate technology packages for establishing productive pastures on any land class capable of being worked with wheel tractors (Teitzel and Middleton 1983). We expected that adoption of the technology would be rapid.

Unfortunately, farmers viewed the results with a great deal of scepticism. They felt that information provided by the experiments was fragmented and too specific to a rather artificial set of experimental conditions. Additionally, there was very little information on the likely level of beef production from the new pasture technology or on the longevity of the pastures. Because previous plantings of improved pastures had died out after a few years, farmers were not convinced that the pastures would be sustainable. Nonetheless, answers to both questions were required for any sensible economic appraisal.

It was clear that such new technologies could only be realistically appraised within the context of whole-farm management systems. There are now many texts on agricultural systems research (Dalton 1975, Remenyi 1985). The remainder of this paper outlines the various types of activities undertaken by our small research group to determine the productivity, sustainability and profitability of alternative pasture systems for the beef industry in the humid tropics of Queensland.

Preliminary Assembly into Management Packages (Conceptual Modelling)

This is the first step in synthesising available technical information into management packages. In the Queensland humid tropics, there are 23 land classes with different fertilizer requirements and at least three soil drainage groups. For each of these, there are several pasture species options which may be managed at different intensities with a number of animal options. Farmers, extension officers and researchers contributed to the selection of what we considered to be the most attractive management packages for the range of purposes and land classes. These were then subjected to detailed analyses.

Preliminary Numerical Modelling

Numerical models (generally highly abstracted) of the management options were required for economic analyses. They were also a useful means of formalising the knowledge and/or perceptions of the contributors to the conceptual models. These initial models were usually fairly simple and a computer was not essential but obviously helpful because of the number of permutations involved. Using computers, many factors could be varied simultaneously and the 'what if?' questioning could be more rigorous. Although parameters for some of the options were unknown, estimates of the levels of production required for profitable operation were derived. If we considered that such levels were unlikely to be attained in practice, then that particular management option was rejected.

Physical Modelling of Management Options

The next step was to take the most attractive of the options and quantify their productivity and stability under simulated commercial conditions. Small physical models (1.6–2.4 ha) employing a range of management options were established on a range of land classes on farms. The approach was similar to the farmlet studies of Murtagh (1980) and Bell (1976) and the full-scale systems studies of Eadie and Maxwell (1975).

For each land class, a control management system simulated the best system in current commercial use. A comparison of the performance of this experimental control to actual commercial performance provided a test of the validity of the modelling exercise.

The first objective was to determine the stable attainable production levels for each of the management systems. This took seven years. It was not until one year after planting that any of the pastures could be safely stocked at levels attained commercially by the 'control system'. It was another year before pasture yields were sufficiently different to justify increased cattle numbers on the higher-yielding pasture systems. Cattle numbers were increased in the same way as a farmer would increase his herd. By year seven, the most productive system still had the highest pasture yields despite carrying 30% more cattle.

To confirm that even higher production levels were not sustainable, we gradually increased stock numbers beyond those established by the first stage of experimentation. These stock increases resulted in a steady reduction in animal growth rates and a fairly rapid weed invasion of systems with the lowest pasture yields. After two years of deliberately heavy grazing, cattle were losing weight in all systems and weed invasion was severe. This was regarded as the 'crash point' of the experiment.

The final phase of the study was the 'regeneration phase'. After reaching their crash points, the pasture systems were destocked and weeds were slashed. Three months later, stock were again introduced and numbers gradually increased. Two years after the 'crash point', the desirable pasture species had recovered to dominate weeds and stocking rates were again at the 'stable attainable' levels. Replanting was not required in any of the pasture systems under study.

The production parameters established during the five-year 'stable attainable' phase were thus regarded as good estimates of the sustainable operating levels of the management options on a 'year in, year out' basis.

Numerical Modelling of Biological Processes

Computer modelling procedures involving rate processes and stochastic elements have been regarded as important tools for studying complex and dynamic biological processes (de Wit and Goudriaan 1974, Dalton 1975, Dent and Blackie, 1979). Simulation models (McKeon et al. 1985) have attempted to link all the processes involved in climate–soil–plant–animal production systems. They may be regarded as alternatives to the physical modelling procedures described above. Large computer capacity and well developed computing skills are required. Dynamic simulation models have been useful for giving researchers an increased understanding of the systems under study. However, there are not many examples where they have been used for farm management decision-making.

Bio-economic Modelling

This can be a logical extension of the above simulations of biological processes. In practice this requires considerable computing skills and results in very large and complex models. However, a distinction between 'scientific' and 'practical' models is made by Neeteson and Van Veen (1988), and scientific models are becoming more refined whereas practical models are becoming increasingly simplified.

A wide range of computer modelling procedures is now available. However, because of the large data sets required for a realistic numerical description of the biological, physical and economic aspects of whole-farm production systems, the choice is probably limited to either dynamic simulation or linear programming.

Simulation has the advantage of allowing a realistic description of the dynamic biological processes. However, as mentioned earlier, whole-farm simulation models have been complex and cumbersome to operate. Additionally they have limited analytical capacity and there has been a tendency for operators to become bogged down in endless trial-and-error simulation runs.

Because standard linear programming (LP) algorithms are deterministic and linear, there is a tendency to regard them as not very appropriate means of representing biological systems. However, with the now ready availability of very powerful LP packages, it is possible to construct LP models which approximate non-linear and non-deterministic situations. In a study by Teitzel et al. (1986), each model solution was deterministic, but a sequential series of experimental manipulations of the model provided a series of moving optima, an approach which is clearly non-deterministic. Additionally, individual model solutions provide sensitivity analyses of variables under management control. Similarly, although the relationship between data points in an LP matrix is by definition linear, the practical representation of non-linear biological relationships is not insurmountable. For instance, in the above study, monthly cattle bodyweight changes and monthly carrying capacities of the land/pasture units were represented by a series of lines of different slopes which, when connected on an annual basis, can represent the known non-linear relationships with time. Such models are powerful tools for experimenting with selected systems to optimise the integration of components and to identify the most important knowledge gaps and weaknesses.

Management Decision Support Models

The large bio-economic models described above fit into this category. However, because of their size, they generally require a main-frame computer.

Practical alternatives are provided by a number of management decision support packages now available on personal computers. Spreadsheets, database management systems and graphics packages have been very useful for highly abstracted comparisons of alternative management systems. Simple spreadsheet models have been particularly useful in highlighting the differences between options to farmers, bankers and other non-scientific groups. Packages used here are also useful for the preliminary numerical models mentioned earlier.

A more recent development has been the use of expert systems concepts. Jones (1989) describes five groups of expert systems. First, he describes heuristic expert systems which are designed to mimic the knowledge of a tried and true expert. Secondly, real-time expert controls that use an expert's knowledge to build decision tables for use with feedback sensor data to regulate control systems are described. Thirdly, model-based expert systems that link simulation models and expert systems to facilitate the use of proven models and/or interpretation of results, fourthly, expert databases that facilitate the search for the most relevant information and, finally, problem-specific shells are developed to enhance the application of expert systems concepts to agricultural problems.

A detailed treatise of agricultural decision analysis is given by Anderson, Dillon and Hardaker (1977).

Demonstration Farms

While the computer modelling activities mentioned previously provide additional information and increase our understanding, there are credibility problems. Even the physical modelling experiments were regarded by farmers as somewhat unreal. There were doubts about the validity of extrapolating from the small model to a large farm. Additionally, there was a perception that model farmlets were over-managed and that labour and machinery inputs were unrealistic on a large scale. Conversely, scientists believed that production estimates from the physical models were overly constrained by carefully defined experimental procedures required for objective comparisons of the different systems.

To resolve this conflict, the most favoured pasture management systems were established on a whole-farm scale under the watchful eyes of management committees which included farmers. All inputs (man hours, machinery hours, fertilizer, seed, cattle, etc.) and outputs (cattle sales) were carefully recorded and costed.

These demonstration units provided some of the most carefully measured input data (particularly on labour and machinery) for the bio-economic and decision support models discussed earlier. Such data from commercial farms were generally just 'best estimates'. On the other hand, output from the demonstrations provided useful standards for validating the computer models.

These demonstrations created a good deal of farmer interest and were an important influence on the adoption of new technology.

Monitoring of Commercial Developments

Our physical modelling activities and demonstration farms could only be established on a few sites representing a very limited number of land classes. However, commercially, the technology could be applied to all land classes and sometimes in ways not envisaged by researchers. We therefore began careful monitoring of selected farmers to provide increased understanding and to facilitate early discovery of emergent problems. We established transects on selected land classes and pasture types and initiated stock movement recording programs.

This monitoring has provided us with early warning of possible flaws in the new technology and has facilitated rapid investigation of the causes. Our most frequent problems were with farmers overestimating their area of improved pastures (resulting in over-stocking) and with inaccurate application of fertilizers (resulting in weed invasion of the under-fertilised sections).

Conclusions

Conventional procedures used in agricultural research (largely developed in temperate countries with a long history of agricultural research) have limitations when applied to the development of industries in new regions or environments where there is no long-term experience with that industry. The establishment of a beef industry on infertile soils in the humid tropics of Queensland is an example. The establishment of ruminant industries under plantation crops is likely to be another.

In the Queensland example, because there was no viable farming system in operation, farmers wishing to develop a beef enterprise needed guidance on the synthesis of available research information into practical farming systems. Conventional research programs were able fairly quickly to identify a range of pasture plants which would grow on the infertile soils when mineral deficiencies were corrected. However, the researchers themselves were initially uncertain as to how the results of the experiments were likely to contribute to improvements in productivity and sustainability, let alone profitability.

A whole-farm approach was particularly important in this situation. A number of methodologies were used to study the integration of new or alternative technologies into farm management systems. Physical and computer modelling activities were useful for determining the productivity, sustainability and profitability of alternative systems. Farm survey and monitoring activities were useful for gathering information, increasing understanding and validating research.

Application of the various methodologies was critical. Conventional experimentation on farms led to the establishment of close contacts between researchers and farmers and this enhanced the quality of the information for industry appraisal. Data from the experiments were the building blocks of computer models. Knowledge gaps and sensitive areas, isolated by the models, in turn led to follow up conventional experiments which in turn led to better computer models.

These procedures have been used reasonably successfully in the beef industry in the humid tropics of Queensland. Here, there are commercial examples of grass–legume pastures which have been continuously stocked at 2.5 beef cattle/ha producing around 450 kg liveweight gain/ha/year. After more than 20 years producing at these levels, the pastures are still in excellent condition. More recently, the farming systems studies have indicated that (due to increased beef prices) more costly N-fertilised grass pastures are more productive and more profitable. These systems have maintained stocking rates of 5 steers/ha and produced around 900 kg liveweight gain/ha/year for more than ten years.

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The Potential and Prospects for Improving Forages under Rubber in Malaysia

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Abstract

Sheep integration with rubber has great potential in Malaysia. However, animal productivity and income potential from sheep rearing is unattractive under the current management system. There is a need for improved forages which are capable of increasing sheep productivity. There is also scope for altering the conventional rubber planting system to a hedgerow format which would allow greater light penetration, particularly in mature plantations. Much research is still needed before definite recommendations can be put forward.

THE integration of sheep with plantation crops is relatively new in Malaysia but progress during the last five years has been encouraging. The Rubber Research Institute of Malaysia (RRIM) first conducted research on sheep integration under rubber in 1975 and substantial basic information has been gathered since that time (Tajuddin and Chong 1988).

The main problems in raising sheep under rubber are the poor animal productivity achieved due to low forage productivity and our poor understanding of how best to utilise native forages. This paper highlights some of the problems and constraints currently faced and suggests some prospects for the introduction of improved forages under rubber in Malaysia.

Area under Rubber

Malaysia is the world's leader in the rubber industry in terms of area planted and rubber produced. The total area cultivated with rubber in 1988 was 1.86 million ha (Peninsular Malaysia, Sabah and Sarawak). Smallholdings, of which the majority are less than 2 ha, represent 76.6% of the area in Peninsular Malaysia (Table 1).

Table 1. Area under rubber in Malaysia (1988).

Region	Area (ha)
Peninsular Malaysia	
Estates	367 300
Smallholdings	1 205 100
	1 572 400
Sabah and Sarawak	288 300
Total	1 860 700

Source: Ministry of Primary Industries (1990).

Sheep Population

The sheep population in Malaysia in 1965 was only 37 000 head. However, there has been a phenomenal increase in population particularly in the period from 1980 to 1989 in which the population has increased from 59 000 to 168 200 head (Table 2).

At present, sheep integration with plantations occurs mainly under rubber and oil palm. Various government agencies and private estates carry out commercial projects rearing from a few hundred to more than a thousand sheep per project. The total number of sheep reared by government agencies and private estates under plantations was 74 000 head or 44% of the total sheep population in 1989 (Table 3).

Grazing Saves Weeding Cost

The remarkable interest in rearing sheep under rubber and oil palm is due mainly to the fact that sheep are used as an agent of biological weed control. Sheep graze on the naturalised undergrowth thereby reducing the cost of weeding. Weeding costs under rubber can be reduced by sheep grazing by 18–36% (Tajuddin et al. 1990). This can be achieved because 60–70% of the weeds present under rubber are palatable to sheep (Wan Mohamad 1978).

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Table 2. Sheep population in Malaysia.

Year	No.
1965	3 000
1980	59 000
1985	78 000
1986	90 359
1987	128 383
1988	148 159
1989	168 200

Source: Ani Arope (1988) and Department of Veterinary Services (1990).

Table 3. Sheep population under rubber and oil palm (1989).

Sector	No.
Government agencies:	
RISDA	12 000
FELCRA	12 000
FELDA	12 000
RRIM	2 500
DVS	10 500
LKPP	4 000
SEDC	8 000
Private estates:	
Guthrie	8 000
Other estates	5 000
Total	74 000

Mutton Demand and Importation

Mutton (sheep and goat meat) is a high-priced meat acceptable to Malaysian consumers. The total demand in 1988 was estimated at 6740 t. However, the country produced only about 500 t and the remainder (6240 t or 93%) was imported at a cost of 23 million ringgit (Ahmad Mustaffa 1988). There is a very good market for locally produced mutton.

Potential of Sheep Integration

The plantation areas under rubber have great potential to be used for rearing sheep. It is estimated that 20% of the area under rubber can be integrated with sheep provided there are adequate productive ewes available to be used as basic stock. At a stocking rate of 3sheep/ha, the total number that can be reared is approximately 1.08 million head. With this population, it can be estimated that the total annual production of mutton would be around 12 960 t (assuming 1.2 effective annual lamb production, 25 kg/head and 40% dressing percentage). This would meet the annual domestic demand for mutton and there may be some surplus for export.

Present Constraints in Forage Utilisation

Although the potential for sheep production is good, there are several constraints, the major being in the areas of forage productivity and utilisation.

Under immature rubber (3–5 years), the standing dry matter yield of forage was estimated at around 1200 kg/ha and the theoretical stocking rate (at six grazing rounds per year) was estimated at 13 sheep/ha. However, in subsequent years under mature rubber, the standing dry matter yield declined sharply to only about 520 kg/ha and the theoretical stocking (at four grazing rounds per year) dropped to only 3.7 sheep/ha (Chee et al., these Proceedings).

The above situation leads to difficulty in stocking rate planning. The potential income and gross profit on a long-term basis is also not very encouraging. In the case of smallholders owning 2 ha, the potential gross profit per smallholder from rearing sheep under mature rubber is very low, estimated at around 257 ringgit/year (at 3.7 sheep/ha × 2 ha × 1.2 effective annual lamb production × 29 ringgit profit per lamb).

Thus there is a great need to increase the productivity of forages under mature rubber in order to increase the potential income of smallholders from sheep-rearing. An increase in forage supply means an increase in stocking rate and therefore an increase in the total number of sheep that can be reared per unit land area. This would lead to a higher income for smallholders.

Socio-economic Constraints in Improving Forage Supply

Improving the productivity and sustainability of forages under plantation crops is not as simple as it sounds. There are socio-economic constraints hindering this sort of development. The main constraints are:

(1) high cost of establishment of forages compared to conventional legume covers planted under rubber; (2) improved forages may require a higher level of management and fertilizer application; (3) it may be difficult to obtain forage seed commercially and the price of seeds may be expensive; and (4) smallholders and estate workers have poor knowledge of and experience in handling forages.

Prospects for Improvement of Forages

The prospects for improving forages under rubber are considered to be very good and their role in improving animal productivity and income is evident. However, there is a lot that needs to be done.

In the case of the conventional system of planting rubber at 6 x 3.7 m (450 trees/ha) or 9 x 2.5 m (444 trees/ha) spacings, shade-tolerant species of legumes and grasses are required to improve the productivity and sustainability of forages as the rubber matures. It may be possible, also, to move to a hedge-planting system of rubber of 22 x 2 x 3 m (450 trees/ha) in which the light penetration between the hedges is greatly increased and shade tolerance may be of lesser importance.

Desirable Characteristics of New Pasture Species

It may be asking too much to obtain all-purpose new pasture species that will meet all the requirements of sheep integration under rubber. Nevertheless, the desired characteristics of new pasture species are:

(1) a combination of legumes and grasses;
(2) quick early establishment for weed and erosion control;
(3) high yield potential even when light transmission is as low as 20%;
(4) ability to withstand grazing;
(5) commercial seed production possible;
(6) low maintenance and manuring requirements; and
(7) non-competitiveness with rubber.

Management System of Improved Species

The suggested management system for conventionally planted rubber, taking into consideration the other requirements under rubber of rubber management, is:

(1) plant the conventional species or a new legume mixture at the time of rubber establishment;
(2) at the twentieth month after rubber establishment, spray out 2 m strips in the middle of the rubber interrows and plant the new pasture species (grass only, or legume + grass) on the sprayed strips; and
(3) four months after pasture establishment, or when the rubber is two years old, commence grazing.

With this approach, it is postulated that the cost of establishment of the new pasture species will be minimised and the conventional establishment and maintenance of rubber will not be greatly upset. However, other aspects of forage management and utilisation such as manuring requirement, stocking rate and stocking methods need to be studied.

Scope of Future Research

Despite the suggestions posed in this paper, there are still many grey areas before the potential of improved forages under rubber can be achieved. The following research areas are suggested for consideration.

(1) Establishment techniques for the planting of new species under conventional and hedge-planting systems of rubber;
(2) development of manuring programs for the improved species;
(3) study of strategic grazing method and stocking rate; and
(4) investigation of supplementary feeding requirements.

Conclusions

It is evident that sheep integration under rubber in Malaysia has great potential. However, animal productivity and income potential from sheep-rearing is unattractive under the current management. There is a need to introduce improved forages under rubber in order to increase productivity and improve the sustainability of forages, especially under mature rubber. There is scope for altering the method of rubber-growing to a hedgerow planting system to increase forage yield. Much information is still needed before definite recommendations can be put forward. Thus it is necessary to continue systematic research in this area for the benefit of those involved in sheep integration under rubber or other plantation crops.

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Prospects for Increasing Forage Supply in Intensive Plantation Crop Systems in Bali

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Abstract

The government of Indonesia encourages the integration of livestock and plantation crops, which occupy 29% of the land area of Bali. Almost all the plantation crops are owned by smallholders. Food crop integration is common, and ruminants are often kept in plantations to suppress weeds and remove crop residues, and also for draught purposes.

There is scope to integrate into plantations grasses and herbaceous legumes for feed and soil cover, and fodder shrubs and trees for feed, fence, shade and support for climbers. Forages can be integrated directly (grown underneath the plantation crop) or indirectly (small areas outside the plantation allocated for feed banks) as in the three-strata system.

Constraints to the increased integration of forages into plantation crops include the relatively low income from livestock compared with promising cash crops such as vanilla, a lack of appreciation of the value of forages by farmers, availability of seed or cuttings of improved forages, the cost of establishment and the lack of capital. Demonstration plots of promising forage species need to be established on farmers' fields to demonstrate the value of feed and these can then also be used for multiplication and distribution. The value of the three-strata system is discussed.

BALI has abundant natural resources on which to base a program of intensification of plantation crop systems. The Schmidt and Ferguson classification (Manik et al. 1979) divides Bali into B, C, D, E and F climatic zones, which range from 9 months wet and 3 months dry for the climatic zone B, to 4 months wet and 8 months dry for the climatic zone F. With its 900 - 3000 mm average annual rainfall, Bali can be classified into wet, semi-arid and arid regions. The soil is generally fertile comprising regosol, latosol and mediteran types (Winaya et al. 1980).

Based on land utilisation mapping, the land in Bali is classified into rice-growing areas, other food crop growing areas and plantation crop areas, with intensive and semi-intensive farming systems employed in all three categories.

Most of the population (60–70%) is smallholder farmers and most, if not all, practise integrated farming. Agricultural produce such as food crops is used mainly for home consumption, whereas the products of livestock (cattle and pigs) and plantation crop enterprises are sold mainly for inter-island trade and international export.

Since Bali has become self-supporting in rice, the Provincial Bali Government is encouraging smallholder farmers to diversify into pulse and tuber crops. Furthermore, since Bali is a non-oil-producing province, the government is encouraging intensification of agriculture by increased integration with existing plantation crops. However, the government is discouraging, and even restricting, movement of the plantation crops into the food crop-growing areas.

Present Status of Plantation Crops

The ten plantation crops commonly found in Bali are coconut, coffee, clove, vanilla, cashew nut, cocoa, kapok, rubber, tobacco and capulaga. Other crops found in certain areas are pepper, ginger, tumeric and medicinal plants. Coconut, coffee and kapok plantations have been established for about 65 years, clove, vanilla and tobacco for 10–20 years, cashew nut, cocoa and capulaga for only 5–10 years. Since most of the plantation crops are grown on undulating country, the government has issued planting guidance so that the shrub and tree plantation crops can serve also an hydrologic function on steeply sloping land.

In 1980, the total area of plantations was 89 260 ha or 16% of the total agricultural land area. Over the past ten years, the increase in area planted to plantation crops has been rapid and in 1989 the figures were 163 520 ha and 29% respectively. However, following the International Coffee Diversification

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Program and the Provincial Bali Government Coffee Mapping Program, the area of coffee plantation has been reduced. On the other hand, the area of clove, vanilla and cocoa is increasing through intensification and integration, since such plantation crops are becoming sought-after export commodities.

Almost all plantation crops (98%) are owned by smallholders. The remaining 2% is owned by commercial enterprises. There are 548 900 smallholder farmers with farm areas varying from 0.11 to 0.46 ha and only five commercial enterprises with areas varying from 185 to 1380 ha. Smallholders owning more than one ha of plantation usually lease or contract part or all of their plantation to other farmers. Even though management is largely dependent on the lessee or contractor, these de facto farmers are usually reluctant to make any changes without the consent of the owner. Average yields are marginally higher for smallholders compared with commercial producers.

Some plantation crops such as vanilla, tobacco, capulaga and rubber require continuous attention, while others such as coconut, kapok, cocoa and cashew nut require only seasonal attention. For smallholder plantation crops, permanent labour is usually provided by the family, while seasonal labour is partly recruited from the village. For commercial enterprises, on the other hand, the permanent and casual labour requirements are recruited on a contract basis. Of the 5.8 million work-months of labour used in 1988, 99% was for smallholder plantations.

Except for coconut and kapok, the price of plantation crop commodities fluctuates widely. Such price fluctuations coupled with relatively low quality of produce and high maintenance costs have resulted in a low and often marginal benefit for smallholder farmers.

The Provincial Bali Government (through the Department of Plantation) is providing training and services to smallholder farmers by direct contact, through the mass media and through demonstration plot programs. For some plantation commodities, the government is also supplying seeds, clones and stump planting material of superior quality. In diversifying the tourist economy of Bali, the Provincial Government is planning to use plantations as one of its tourist attractions.

Present Plantation Crop Integrated Systems

Food crop integration

Food crops commonly integrated with plantation crops include corn, red-bean, peanut and cassava. The integration of food crops is usually for 8–9 months of the year, while for the other 3–4 months the land is usually left idle and becomes invaded by weeds. In this system, food crops apparently do not compete for water since the food crops are grown during the wet season, and by the time moisture shortage becomes a constraint, the food crop has been harvested.

Grain and tubers are used for home consumption, and the straw residues are fed to livestock. Most farmers claim that yields of plantation crops integrated with food crops are higher than without food crop integration.

Vanilla is not commonly integrated with food crops, while coffee, cocoa, rubber and clove are usually interplanted with food crops for the first 3 - 4 years of the growing period of the tree crop. Coconut can be integrated with food crops both during the early growth and production periods.

Food crop integration has some important social bearings. Farmers who visit the field daily to look after their food crops are also indirectly looking after their plantation crop. Furthermore, land sown to food crops will not be trespassed upon.

Estate crop integration

Cocoa, vanilla, clove and capulaga are the main estate crops commonly grown under coconuts. The planting space, leaf canopy structure and height of the coconut ensure sufficient sunlight for the growth and production of these crops. In the case of vanilla, a lower light intensity is desirable, and this is provided by the leaf canopy of the support shrub.

Nutrient competition does not appear to be a major constraint in this very intensive form of integration, since farmers regularly apply artificial fertilizers or livestock manure. However, in the case of vanilla, the very intensive integration of grass, vanilla, shrub and coconut layers may result, in the long-term, in competition for soil nutrients.

Livestock integration

In nearly all the plantation crops, ruminants are kept as clearers of weeds and crop residues and for draught purposes. In the smallholder coconut plantations, poultry and pigs are kept to consume the byproducts of the oil-processing cottage industry.

Recently, smallholders with clove and vanilla plantations have preferred to keep goats rather than cattle. It is claimed that goat manure will release nutrients more slowly and over longer periods than cattle manure.

Livestock are usually permanently stalled or tethered for grazing during the day and stalled at night. In the vanilla-growing areas, poultry are kept in cages so that the birds do not scratch the roots of vanilla.

When the vanilla and clove plantations were first established in Bali, it was postulated that ruminants would no longer be needed, as little roughage was available and draught power was not required. However, with the presence of volunteer grasses, the use of shrubs as climbers that have to be lopped regularly, and the need for barnyard manure, the integration of ruminants has become even more important. Since the ruminants integrated with plantation crops are generally permanently stalled and no energy is expended in grazing, it will be interesting to note whether ruminants in plantation crops perform better than those integrated in the food-crop growing areas.

Even though livestock are integrated with plantation crops, they will remain a secondary activity. In most farming families, the children or the wife, rather than the father, look after the livestock. The presence of livestock may in some cases cause damage to or interference with plantation crops if not managed properly. In commercial enterprises, raising livestock is not encouraged, since the workers are paid to manage the plantation and not to keep livestock.

The number of livestock raised is not dependent on the area of plantation, but rather on the size of the farming family. On average, each family keeps 4 pigs, 10 kampung chickens, 2 cattle or 2 buffalo and/or 3 goats.

Forage integration

Forage integrated with plantation crops can be in the form of grass, herbaceous legume, or fodder shrubs and trees. *Erythrina variagata* and *Leucaena leucocephala* are fodder tree legumes commonly used as shade plants in coffee plantations, while *Leucaena* is the most commonly used support for vanilla. However, due to *Heteropsylla* insect attack, it has been replaced by *Gliricidia sepium*, *Erythrina* sp. and *Lannea corromandilica*. In smallholder plantation crops, grass and herbaceous legumes are not planted, but grow naturally as volunteer weeds. There are 26– 31 native grass species with forage yields (cut twice a year) varying from 1.7 to 2.6 t DW/ha/year (Nitis et al. 1980). In commercial plantation crops, legumes such as *Centrosema*, *Calopogonium* and *Mimosa* are grown for their green manure value.

The fodder shrub and tree species used as shade are not usually cut. The shrubs used as support for vanilla are usually lopped twice a year; while the shrub and trees used in living fence lines are cut whenever needed as forage or whenever they cause inconvenience. In vanilla plantations, there are about 100–200 shrubs/ha, while in living fences there are 10 000–15 000 shrubs and 20–40 fodder trees/ha. The leaf yield (lopped twice a year) of the 10–15-year-old fodder shrubs and trees varies from 5.5 to 10.4 kg DW/tree/year (Nitis et al. 1980).

Since grass, shrub legume and fodder trees are not specially grown for forage, shortage of livestock feed is not uncommon, particularly during the dry season.

Scope for Greater Use of Forages in Intensive Plantation Crops

Choice of plantation crop and forage species

During the early growth and the later production stages of most tree crops, grass and herbaceous legumes can be integrated as cover crops, and fodder shrubs and trees can be used to provide shade or support.

Although the main objective of integrating forages into plantation crops is to increase forage supply, the secondary objectives of cover crops—shade, climber support, firewood, timber supply and nutrient recycling—should also be considered to ensure maximum benefits of integration.

Apart from the desirable characteristics normally associated with fodder species, shrub and fodder trees should be able to withstand repeated lopping and be non-deciduous in habit. When used for shade, shrubs and trees should have a pollarded branching habit with a leaf canopy that is not too thick. When used as support for climbers, they should be erect, with a pollarded rather than evenly distributed branching habit. They should have stems which do not peel off, be resistant to root rot, and be able to bear the biomass and saprophytic habit of the climber. They should also be deep-rooted so that they do not compete for nutrients with the plantation crop and can withstand the prevailing wind.

Using improved varieties appropriate to the type of plantation crop, and coupled with strategic cutting management and fertilizer application, the yield of grass, herbaceous legumes, shrubs and trees can be increased (Manidol 1984, Rika 1985, Horne et al. 1985, Nitis et al. 1989).

Forage production systems

Forage can be integrated directly or indirectly into plantation crops. Direct integration implies that the forage is grown within the plantation crop area, while indirect integration implies that the forage is grown in the vicinity of the plantation crop. In both these systems, the forage can be cut and carried for livestock feed. The likely forage yield from various forage integration systems has been calculated in Table 1.

With direct integration, herbaceous forages and shrub and tree fodders may be grown without following any pattern. In this system, the area of herbaceous pasture will be the same as the area of the plantation crop while the number of the shrub or trees may vary from 100 to 200 plants/ha.

There are also a number of more formally identifiable systems of direct integration. In alley cropping, the grass and herbaceous legume can be grown as strips, while the fodder shrubs and trees can be grown as hedgerows between the rows of the

Table 1. Predicted forage yield from one hectare of plantation crop using various integrated forage planting systems.

Production system	Forage types	Size	Yield (t DW/year)	Plantation crops
Direct integration				
Intercropping	a) Pasture[2]	1.0 ha	14.6	All plantation crops (except vanilla and pepper)
	b) Shrub[3]	75 plants[1]	0.2	
	c) Tree4	75 plants	0.6	
	Total (a+b+c)		15.4	
Alley cropping	a) Pasture	0.8 ha	11.7	All plantation crops
	b) Shrub	1500 plants	4.5	
	c) Tree	150 plants	1.2	
	Total (a+b+c)		17.3	
Shade	a) Pasture	0.8 ha	11.7	Early growth stage of all plantation crops
	b) Shrub	75 plants	0.2	
	c) Tree	75 plants	0.6	
	Total (a+b+c)		12.5	
Support for vanilla or pepper	a) Pasture	0.8 ha	11.7	Vanilla and pepper
	b) Shrub	125 plants	0.4	
	c) Tree	125 plants	1.0	
	Total (a+b+c)		13.0	
Fence	a) Pasture	0.8 ha	11.7	All plantation crops
	b) Shrub	3000 plants	9.0	
	c) Tree	60 plants	0.5	
	Total (a+b+c)		21.1	
Indirect integration				
Feed bank	a) Pasture	1.0 ha	14.6	Indirect integration
	b) Shrub	300 plants	0.9	
	c) Tree	150 plants	1.2	
	Total (a+b+c)		16.7	

[1] Average value; [2] pasture: 4.5–24.6 t DW/ha/year (Manidol 1984); [3] shrub legume: 2.0–4.0 kg DW/tree/year (Horne et al. 1985); [4] fodder trees: 5.6–10.3 kg DW/tree/year (Nitis et al. 1980).

plantation crop. The spacing of the shrub rows may be 0.5–1.0 m (1000–2000 plants/ha), while the spacing of tree rows may be 5–10 m (100–200 plants/ha). The area of the pasture will be 80–90% of the total area.

When fodder shrubs and trees are used for shade, they can be grown in parallel or diagonal patterns under the plantation crops. The pasture can be grown as an intercrop or as an alley crop. In this system, there may be 100 - 200 shrubs and/or fodder trees/ha with 0.8 - 1.0 ha pasture/ha of plantation crop. When rows of fodder shrubs or trees are grown to support climbers, understorey pasture can again be grown as an intercrop or an alley crop. In this system, there will be 200 - 300 shrubs or fodder trees/ha with 0.8 - 1.0 ha pasture/ha of plantation crop. When used for living fences, the fodder shrubs and trees may be grown as a fence surrounding the plantation crop with herbaceous pasture grown as an intercrop or an alley crop. Shrub spacing may be 10–20 cm (2000–4000 shrubs/ha) and tree spacing 5–0 m (40–80 trees/ha) with around 0.8–1.0 ha of herbaceous pasture/ha plantation crop.

In indirect integration, special land may be allocated as an intensive feed bank. Depending on the planting density, in one hectare there may be 100– 200 trees/ha and 200–400 shrubs/ha and pasture.

Forage utilisation

The forage may be utilised either in fresh or conserved form by livestock. In wetter areas, where sunshine is limiting, conservation in the form of silage is preferable. In dryland plantation crops, conservation in the form of hay is preferable.

Shrub and tree fodders preferably are conserved in situ by adjusting lopping frequency. To ensure year-round forage supply, grass and herbaceous legumes should be cut mainly during the wet seasons, while fodder shrubs and trees should be cut mainly during the dry season.

Major constraints

Data are not readily available for forages that are adapted for integration with plantation crops. Seeds and cuttings of new forage species are not only difficult to obtain but also are too expensive to establish in smallholder plantation crops. Demonstration plots should be established by government and non-government agencies to act as nurseries to supply seeds and cuttings for the interested plantation farmers.

The area of smallholder plantations is relatively small, so that the forage available is not sufficient to feed livestock for meat production. Using highly productive cultivars, more intensive methods of forage integration, and strategic defoliation and conservation measures, it should be possible to increase forage supply without increasing the land area.

Smallholder farmers currently do not plant grasses and/or legumes as forages under their plantation crops. However, they do grow fodder shrubs and trees for shade, supports for vanilla or protection of plantation crops. Commercial enterprises, on the other hand, grow legumes for green manure but not for forage. Demonstration plots should be established in farmers' own fields, so that the smallholder farmer can appreciate the importance of good forage crops, not as a cover crop, shade or support, but as a source of feed for livestock.

Plantation crops are often a high-profit enterprise, so the plantation crop owner may be reluctant to take on 'side-line' activities such as growing forage and keeping livestock.

In smallholder plantation crops, most of the routine work is carried out by family labour. Therefore the role of children and housewives in keeping livestock should not be overlooked, and with some practical guidance and training their management can be improved.

Capital to establish forage and to buy livestock to integrate into plantation crops may be another limiting factor, although farmer groups and smallholder farmers, with a recommendation from the Departments of Plantation and Animal Husbandry, can obtain special bank loans.

A Possible Solution

A possible solution to the problem of inadequate forage in intensively cultivated plantation crops is now proposed. It comprises an integrated production model in which each ha of land is divided into an 0.8 ha core area for the plantation crop and a 0.2 ha buffer zone area using the three-strata forage system (TSFS) developed in Bali (Nitis et al. 1989) (Fig. 1). The plantation crop area may be a monoculture or may be integrated with a forage crop. The TSFS methodology

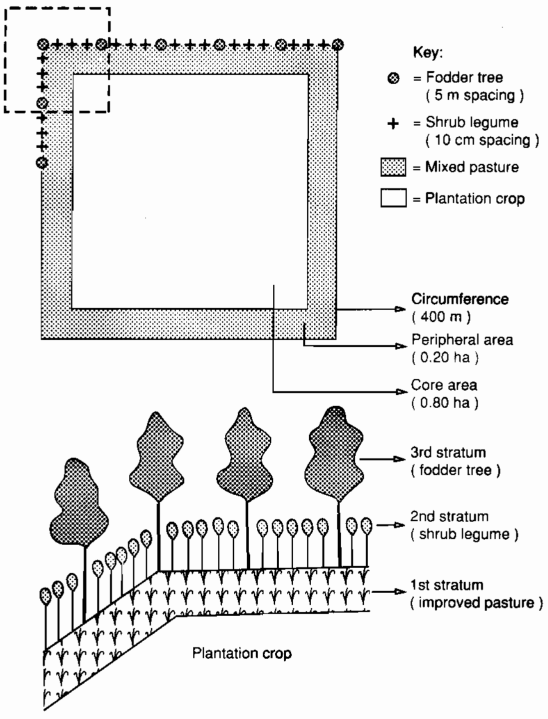

Fig. 1. Proposed integration of the three-strata forage system with plantation crops.

is developed in the peripheral area, surrounding the core area, and along the circumference. The 0.2 ha peripheral area comprising mixed pasture (first stratum), the 400 m circumference containing 4000 shrubs (second stratum) and 80 fodder trees (third stratum) have the potential to produce a forage yield of 15.5 t DM/year. Animals integrated with the plantation crop can be either stall-fed or tethered for grazing.

Based on data obtained on the integration of forage and livestock in plantation crops in the TSFS, the expected outcome is:

(1) plantation crop yield will be reduced, since the area of plantation is reduced from 1.0 to 0.8 ha;

(2) forage yield will be increased due to the presence of 0.2 ha of mixed pasture, 80 fodder tree legumes and 4000 shrub legumes. When forages are also integrated in the plantation crop area, the forage production will be even higher;

(3) there will be increased carrying capacity of the land;

(4) security of the plantation crop will be increased, since TSFS will act as protection;

(5) soil structure and fertility will be improved

due to the presence of nodulated legumes, root debris of the TSFS and manure from the livestock;

(6) firewood will be available from the branches of the shrubs and trees; and

(7) other on-farm activities will be increased (such as Kampung chicken-raising, honey bee-keeping, backyard snail-raising and plantation tourism).

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Prospects for Integration of Forages for Ruminants into Coconut Plantations in North Sulawesi

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Abstract

There are about 250 000 ha of coconuts in North Sulawesi, mostly cultivated by smallholders with an average farm size of 1.7 ha. The industry employs approximately 60% of the total labour force in agriculture and contributes about 80% of the province's exports. Land under coconut palms is mainly used for subsistence food production and cattle are raised in a traditional way for draught purposes with little adoption of modern practices. The market prospects for high quality meat are encouraging and should provide incentive for further investment in pasture research and improved husbandry practices.

Various studies have indicated possibilities for the modernisation of cattle and goat farming by smallholders through improvement of forage production, breeding and better cattle production systems. However, smallholder adoption of new technologies remains in doubt as the technologies have not been financially and economically evaluated at the 'on-farm' level.

INDONESIA, an archipelago with a population of 175 million, is the world's second-largest coconut producer after the Philippines. Coconuts are cultivated throughout the archipelago; approximately 10 million people obtain their livelihood from about 200 million palm trees on 3 million ha of coconut farms. Approximately 10% of the total coconut area of Indonesia is situated in North Sulawesi, the most important coconut-producing province in Indonesia.

North Sulawesi, with a land area of 2.57 million ha, occupies the eastern section of the long northern peninsula of Sulawesi. The mainland section is about 560 km long and never more than about 80 km wide; the Sangir and Talaud Islands stretch to the north, with the northernmost islands lying closer to the Philippines than to Manado. The climate is equatorial with a heavy rainfall spread evenly through the year, though it is drier between May and September. Leaching is severe under such conditions when the forest cover is removed. But, fortunately, the Indonesian 'ring of fire', or arc of active volcanoes, passes through Minahasa and the Sangir Islands, giving rise to fertile soils from volcanic deposits.

Nearly 60% of the land area of North Sulawesi is covered with forests, but plantation crops (mainly coconuts) form a significant part of the agricultural land (Table 1). According to an aerial survey reported by Babcock and Cummings, cited by Sondakh and Jones (1989), land identified as suitable for intensive farming occupies only 297 000 ha or 11% of the total land area. However, Table 1 suggests a total farming area of 658 000 ha which considerably exceeds the suitable farming area. It is clear that more and more farmers have recently been moving to the hillsides in their quest for land, and this has resulted in serious erosion problems. Fortunately, in most areas, and especially in Minahasa Province, the hillsides are used mainly for coconut palms, a land use which does not lead to erosion.

Despite the leading role of rice in the food crops subsector, the province continues to import between 40 000 t and 50 000 t of rice per year. The potential for irrigation is estimated to be at least 51 000 ha, but effectively only about 20 000 ha have been fully irrigated. The second food crop is maize. In addition, the production of soybeans and, to some extent, peanuts and vegetables, has been rising rapidly.

Table 1. Land use in North Sulawesi.

Land use	Area ('000 ha)	Percentage
Forests	1500	58.1
Food crops	328	12.7
Plantation crops	330	12.8
Urban settlements	48	1.9
Lakes and rivers	30	1.2
Grasslands	26	1.0
Other (swamps, marshes, etc.)	316	12.3
Total	2578	100.0

Source: Sondakh and Jones (1989).

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Plantations have long been the backbone of the economy. Kabupaten Minahasa is the major plantation area, containing over half of the coconut plantations and about two-thirds of the clove plantations. Nutmeg is produced mainly in Sangir Talaud, and coffee in Bolaang Mongondow.

The Coconut Production Subsector

Approximately 250 000 ha of land in North Sulawesi is devoted to coconut plantations producing about 250 000 t of copra per year. About two-thirds of all farming households in the province are coconut farmers with an average cultivated area of 1.7 ha. The industry contributes about 20% of the province's regional income. In addition, about 70% of its foreign exchange earnings come from exports of coconut products, mainly coconut oil, copra meal, and also charcoal and desiccated coconut. Other products of the coconut palm (often referred to as the 'tree of life') such as husks, trunk and palm juice have not yet been utilised. Intercropping is widely practised. Intercrops such as cassava, maize, rice and vegetables enable smallholders to secure their basic needs. About 30% of smallholder farm income derives from intercropping.

There are two main varieties of coconuts being cultivated in Indonesia, the traditional 'tall palms' and the newly introduced hybrid palms. The tall palms, with a density of 100 stems/ha, produce about 1 t/ha of copra with a productive life of at least 60 years in North Sulawesi. The hybrid palms with a density of 144 stems/ha are claimed to produce in excess of 6 t/ha of copra with a productive life of, at most, 40 years. The evaluation currently carried out on hybrids shows that these palms may not be as productive as expected.

The Intercropping Practices

A study by Sondakh (1984) on nearly 200 coconut farms in North Sulawesi showed an inverse relationship between size of coconut area and the proportion of area intercropped (Table 2). Intercropping under coconut palms is possible only if the palms are not too closely planted, e.g. fewer than 175 old tall palms/ha (Burgess 1981). Intercropping is also possible during the initial growth stage of both hybrid and tall palms when light interception is still low. Table 2 further shows that, on average, 35% of coconut land is used for intercropping. The main crops cultivated as intercrops are corn, rice, soybean, groundnuts, cassava, and sweet potato. Rice is mainly confined to the wet season, but other crops are grown in both wet and dry seasons.

The Livestock Subsector

The livestock industry has considerable potential. Pig consumption exceeds the national average, and the poultry industry has expanded rapidly. Cattle production has increased from 190 000 in the 1970s to nearly 300 000 in 1990. Cattle are raised in a traditional way mainly for draught work on farms. The province exports about 10 000 cattle annually to Jakarta, Kalimantan and Irian Jaya. These cattle are mostly male and/or females more than 8 years old. The meat is often of low quality.

Recently Alamtaha (1990) carried out a survey of 50 coconut farmers in Kabupaten Bolaang Mongondow (Table 3). The survey showed that, on average, one ha of agricultural land carried approximately 0.5 cattle. This is similar to the carrying capacity at the regional level, indicating that agricultural land including coconut land has not been used optimally for livestock production.

Table 2. Proportion of coconut area used for intercropping for different farm size categories.

	Farm size				
	Small	Medium	Large	Very large	All farms
Coconut farm area ranges (ha)	0.50-1.35	1.36-2.66	2.67-4.00	>4.01	0.50-8.00
Average area (ha)	0.96	1.94	3.41	6.16	2.64
	(0.23)*	(0.97)	(0.44)	(1.28)	(1.81)
Area intercropped (ha)	0.67	0.73	1.14	1.52	0.93
	(0.44)	(0.70)	(0.02)	(1.72)	(0.85)
Proportion intercropped (%)	70	37	33	25	35

Note: In the wet season, the coconut land for intercropping may be cultivated with corn and upland rice. In the dry season, the land may be cultivated with corn, soybean and groundnuts.

* Figures in parentheses are standard deviations.
Source: Sondakh (1984)

Table 3. Land use and livestock numbers of 50 coconut farmers in Kabupaten Bolaang Mongondow.

Average land use per family	
Coconuts (ha)	3.46
Cloves (ha)	1.88
Rice field (ha)	0.69
Coffee (ha)	0.16
Intercrops (ha)	0.05
Average number of livestock per farmer	
Cattle	2.60
Goats	2.60
Pigs	0.16
Chickens	7.00
Ducks	0.60

Source: Alamtaha (1990).

The Potential and Constraints for Increased Livestock Production

Future demand for good quality meat is quite promising. The stable and sustained economic growth experienced by Indonesia over the last 25 years has shifted the tastes and preferences of beef consumers from low to higher quality meat. Since income elasticity of meat exceeds unity, market prospects for better quality meat must be good. Unfortunately, the steady increase in demand is not followed by a steady increase in supply. Therefore the stronger domestic demand for good quality meat in Indonesia is mainly met by imports from Australia, New Zealand and North America. Most hotels in Indonesia serve imported rather than domestically produced meats.

Traditionally, the people of North Sulawesi husband cattle not only for draught but also as an asset and as security. In rural areas of the province, cattle ownership affects the social status of farmers. Husbandry practices are, however, traditional. Feeds for cattle are mainly grasses, e.g. lalang (*Imperata cylindrica*) and some legumes growing naturally under coconut palms. Grains and high quality grasses and legumes are rarely fed. Pest control is seldom applied. Vaccination is applied occasionally by officers from Dinas Peternakan. Well planned or well designed breeding programs are nonexistent. The traditional way of raising and breeding cattle is the main reason for the low rate of growth.

The main factors influencing smallholders not to adopt modern cattle farming are:

(1) lack of capital and an inability to afford finance for modern systems of cattle farming;

(2) poor farmers first have to secure their basic needs, which means that they must use their limited land for food crops and not for modern livestock farming practices; and

(3) farmers have no access to improved profitable technologies in breeding, feeding and management of cattle.

The problems of lack of capital at the farm level may not be serious at the macro-level but it is serious at the 'on-farm' level. The majority of coconut farmers are smallholders whose incomes are just sufficient to secure their basic needs, and they are subject to high risks due to wild fluctuations of copra prices. For example, in the last five years, copra prices have fluctuated Rp 150–550/kg.

The problem of lack of capital is further aggravated by the fact that there is no history of technological change in the livestock industries. Over the past 25 years, Indonesia has been very successful in increasing food and export crop productivity but not so in livestock productivity. Rice production increased from 2 to 6 t/ha but the productivity of cattle remained constant. The lack of technological change in livestock production is caused by the lack of research and development in this industry. For example, the use of research funds for pasture and legume production at Sam Ratulangi University was no more than 2% of the total budget in each of the past five years.

Lack of research and information on available technologies at the farm level is the main factor in the comparative disadvantage of livestock production compared to other agricultural commodities. In other words, farmers do not yet believe that it is more profitable to allocate their limited land and capital to increased integration of livestock into their farming system.

Against this, the prospects for increasing farm cattle production are, however, quite promising. Research undertaken by the Faculty of Animal Husbandry, Sam Ratulangi University (Kaligis and Sumolang, these Proceedings) shows that soils and climate in North Sulawesi are suitable for intensive livestock production systems. The team has identified more productive grasses and legumes suitable for North Sulawesi. Unfortunately the technologies already identified have not carried through into on-farm trials, which are necessary for the technologies to be disseminated to farmers.

A study undertaken by the Coconut Research Institute in Manado (Mahmud and Allororung 1989) shows that improvement of 'natural pastures' under coconut palms in North Sulawesi can significantly influence daily weight gain of cattle (see Table 4).

The data show that greater access to planted setaria (*Setaria sphacelata*) pasture improves bodyweight gain. These results indicate that the potential for increasing cattle production through introduction of improved grasses and legumes and related management practices is quite high. The Research Institute also reported that the introduction of intercrops of food crops and/or grasses and legumes under coconut palms may also increase coconut production.

Table 4. Weight gain of cattle fed varying proportions of *Setaria* sp. in addition to a low-quality basal diet.

Feeding regime (% *Setaria*)	Weight gain (g/head/day)
0	-94
20	314
40	526
60	757
80	909

Note: The feeding trial was run over 5 weeks and the basal diet consisted of natural grasses plus concentrates.

Source: Mahmud and Allororung (1989).

Conclusions

The data presented in this paper demonstrate the potential for increased integration of forages and cattle into coconut-farming systems. However, further research, particularly on-farm, is still needed before we can be confident that the new technologies can be disseminated at farm level.

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Integrated Forage – Livestock Systems under Coconuts in the Philippines

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Abstract

The Philippines has 3.2 million ha of coconut plantations which are predominantly owned by smallholders with an average farm size of 3.3 ha. Grazing cattle and buffalo on improved or unimproved pastures is a traditional practice among farmers, and higher animal and coconut production from improved pastures indicate the value of integrating forages with coconuts. Government policies and programs are focused on smallholder farms where prospects for integrating forages into plantation crops are good. The adoption of new practices is restricted by socio-economic and technical constraints.

Coconut Production

AN estimated 3.2 million ha of the total land area (30 million ha) of the Philippines is planted to coconuts (1989 statistical data). Coconut plantations in Mindanao account for more than 50% of this area, and the remaining areas are located mainly in Southern Luzon and Visayas.

Average nut production is estimated at a low 49 nuts/tree/year or about 4649 nuts/ha/year. There are marked regional differences in production ranging from 64 nuts/tree/year in Southern Mindanao to 38 nuts/tree/year in Central Luzon. Approximately 25% of the 401 million trees planted are non-bearing or unproductive.

In a survey of coconut plantations, the Philippine Coconut Authority (1978) reported that only 33% of the coconut area was occupied by small farms of less than 5 ha but that these comprised 91% of the total coconut farm holdings (Table 1).

The majority (71%) of coconut farms are owner-operated with an average area of 3.3 ha/farm. Share-tenanted farms comprise the second largest group (22.3%). The remaining farms are either partly owned, tenanted or managed.

Table 1. Area, number and size of coconut farms.

Farm	Total area		Coconut holdings	
(ha)	('000 ha)	(%)	(No.)	(%)
<5	915	33	653 380	91
5–20	629	22	50 300	7
>20	1256	45	14 300	2
Total	2800	100	718 000	100

Source: Philippine Coconut Authority (1978).

Ruminant Population and Productivity

The Philippine Medium-term Development Plan (1987–1992) has a goal to develop a viable livestock industry with active involvement of the smallholder farmers. Smallholders own 99% of the 2.9 million buffalo and 2.1 million goats, and 87% of the 1.6 million cattle. Between 1980 and 1988 the buffalo population increased at an annual rate of 0.3%, the cattle population declined at 1.9%, and the goat population increased at 3.1%.

The reduction in large ruminant numbers occurred despite a shortfall in beef production, particularly in Metro Manila. To overcome this shortage, 3200 to 4800 cattle per month are imported for fattening. The implementation of the Comprehensive Agrarian Land Reform Law (CARL) is likely to result in a shift from hill-beef ranching to smallholder cattle production systems which include small breeding herds and backyard feedlot fattening projects.

The very high demand for milk and milk products provides smallholder livestock-raisers with an opportunity to increase their incomes by integrating dairy animals into their farming enterprises.

A complementary program on small ruminants to augment meat production is being encouraged by the government. CARL will further expand the number of smallholder farms which are suitable for goat and sheep raising. Sheep and goats are multi-purpose animals which can be slaughtered for home use, sold

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for slaughter or breeder animals or can be raised for milk production. The government, in cooperation with selected private farms, is producing quality breeding stocks for upgrading the native animals owned by smallholders. The production of small ruminants under plantations, i.e. coconut, orchards and rubber, is being encouraged through researcher-managed and farmer-implemented pilot projects. In addition, support services, i.e. credit, health services, provision of planting materials of various forages and market facilities, are being developed jointly by the government and private sectors. The price of goats and sheep is relatively high despite the current disorganised marketing system.

Present Levels of Integration of Livestock in Coconut Plantations

In 1983, it was estimated that about 400 000 ha of coconut land were stocked with cattle, buffalo or goats. A survey of two villages in Santa Cruz, Laguna showed that 67% of farmer-respondents integrated either cattle, buffalo, sheep or goats with coconut production.

In large coconut plantations, cattle are grazed on both improved and unimproved pastures. For example, a large coconut plantation in Albay grazes cattle on fertilised carabao grass (*Paspalum conjugatum*) to fatten and finish beef animals. These are grazed for 60–180 days and gain 0.7–1.0 kg/head/day at a stocking rate of 1 beast/ha. In Davao, fertilised para grass (*Brachiaria mutica*) and guinea grass (*Panicum maximum*) pastures can support 3 breeder cows/ha/year.

A recent study conducted in Sorsogon found that the liveweight gain in buffalo was only 53 kg/ha/year on mature native pasture stocked at 1 head/ha. On native pastures containing centro (*Centrosema pubescens*) animal production was 93 kg/ha/year at a stocking rate of 1 head/ha, and 151 kg/ha/year at 2 head/ha.

In small farms, cattle and buffalo are normally tethered in the plantation. Goats are usually not tethered, unless they are in areas where food crops are intercropped.

Forage Resources under Coconuts

Native vegetation

Observations indicate that the native vegetation under coconuts varies according to location and the intensity of utilisation. In a study of the botanical composition of native vegetation under the coconuts in Sorsogon before and after three years of heavy grazing by buffalo (Table 2) it was found that pasture composition changed from *Imperata cylindrica* and *Pueraria phaseoloides* (puero) domination to one dominated by weeds. Control of stocking pressure and modest fertilizer applications are required to obtain and maintain a desired pasture composition.

A recent survey of native pastures in Santa Cruz, Laguna showed that grasses (48%) and broadleafed weeds (40%) dominated the pastures. Legumes (11%) and shrub/tree leaves (1%) were minor components of the pastures. The major grass species were *Axonopus compressus* and *Cyrtococcum* spp. and the legumes were mainly *Calopogonium mucunoides*, *Centrosema pubescens*, *Moghamia strobilifera* and *Pueraria phaseoloides*. The broadleafed weeds present were *Hyptis rhomboides*, *Mikania cordata*, *Borreria laevis*, *Ageratum conyzoides* and *Borreria repens*.

Table 2. Botanical composition (%) of native pasture before and after three years of grazing by buffalo under coconuts in Sorsogon.

Species	Botanical composition (%)	
	Before grazing	After grazing
Imperata cylindrica	40	1
Paspalum and *Digitaria* spp.	6	22
Pueraria phaseoloides	33	0
Weeds	21	77

Source: Moog et al. (unpublished data).

Improved pastures

Guinea grass and para grass are the most common species grown under coconuts in the Philippines. Extensive areas of para grass pastures are grown in Mindanao, particularly in the Davao area. Guinea grass is more popular in Quezon province among smallholder farms which use a cut-and-carry system. However, nut pickers and gatherers complain that when the grass is allowed to grow tall they have difficulty locating and picking nuts, and that they suffer from skin irritations and cuts from the sharp blades and hairs on the grass. Signal grass (*Brachiaria decumbens*) is becoming popular under coconuts in Sorsogon where it is considered to be more productive than para or guinea grass.

Initially there was some apprehension concerning the growing of improved pastures under coconuts because of the fear that grazing may reduce coconut yields. Recent experience has allayed this fear. Nut yields were found to be 10–30/tree/year in ungrazed areas compared to 30–50 in grazed natural pasture and 80–100 in grazed improved pasture areas.

Limitations to Improving Forages under Coconuts

Lack of experience in animal and pasture management is the major constraint to increased integration. Further, the lack of availability of seeds and planting material of improved pastures restricts the commercial use of recommended forages. Plant evaluation and seed production of promising species need to be undertaken simultaneously.

There are also a number of social and socio-economic constraints to the integration of animals and coconuts. Most coconut plantation owners are absentee landlords who visit their farms only during nut harvest. Seldom do these owners seek opportunities to maximise land use through the introduction of forages and livestock. Coconut farmers with an average land holding of only 3.3 ha have an estimated net income of only 4290 pesos/year which is insufficient to invest in animals or forage improvement. The development and payback period of livestock projects is generally longer than with other agricultural projects and the return on investment is often low. Because of this, credit institutions and entrepreneurs are not attracted, or put low priority on these projects.

The low level of education of most farmers makes extension and development work difficult, slow and expensive since a person-to-person approach has to be used.

However, there is a great need to identify alternative enterprises, since the productivity of many coconut plantations is declining rapidly due to the old age of plantations. Since native vegetation already can support a low number of livestock, the integration of livestock should be encouraged in new areas and enhanced at existing sites. However, providing animals will be difficult because the cattle population is decreasing. Although population growth rates of buffalo and goats were positive up to 1988, numbers have recently been decreasing. Unless there is a vigorous development program to increase the national herd, vast areas under coconuts will remain understocked or unutilised.

The Comprehensive Agrarian Reform Law (CARL) of the government intends to subdivide land into smaller lots, and this will also include coconut plantations. Once the tenants become farmer-owners they will have more interest in making decisions for improvement. The first priority is likely to be the production of food crops, but this will require animals for draught. Once a farmer has animals, he is likely to consider their nutrition, as improvements in the feed offered to animals improves their draught capabilities and their fertility. A grazing trial in Bicol indicated that with livestock integration in coconuts an additional annual income of 1800–4500 pesos can be obtained from buffalo-raising.

The national forage and pasture development program has been concerned with livestock production systems under plantations. The two sites in this program (Bicol and Southern Mindanao) evaluate forages under plantations and develop technologies for integrating forages into plantations. The Philippine Coconut Authority also encourages the integration of livestock under coconuts in its development programs. The improvement of forages, particularly in replanting programs, is an important component of their program.

Conclusion

The integration of forages into coconut plantations has great potential in the Philippines. Plantation areas are underutilised in spite of the capability of the native vegetation to support grazing animals. Experience with guinea grass, para grass and centro-based pastures under coconuts has shown the potential for increasing animal production with the use of improved pasture species.

With agrarian reform in coconut plantations, individual landowners are likely to have more incentive to develop their land, intensify crop production, and more efficiently produce and utilise biomass through the integration of forages and livestock under coconuts.

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Integration of Forages for Cattle and Goats into Plantation Systems in Thailand

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Abstract

The integration of forages for livestock has considerable prospects in Thailand. Forage species must be shade-tolerant and must not be too competitive.

The prospects for integration appear to be best for the higher light transmission and lower value plantation crops such as coconuts and fruit trees, where additional income from livestock would be of major benefit to the farmer. In high value plantation crops such as rubber trees and oil palms, livestock will always be of secondary importance.

Major constraints are the lack of pasture seed and the low and slow return from investment in livestock.

PLANTATION crops occupy about 11% of the total agricultural land in Thailand. The southern region has the highest proportion of land used for plantation crops, and accounts for 74% of the total plantation area in Thailand (Table 1). Rubber is the most important plantation crop in terms of planted area (Table 1) and contribution to the economy of Thailand (Table 3). Although not all of these plantation areas are suited for forage-livestock enterprises, they represent a significant potential for livestock production.

The majority of rubber holdings are small (< 2 ha) while the majority of oil palm producers have large estates (> 500 ha) (Table 2). Most of the smallholder oil palm plantations are organised by government cooperative programs. Coconut plantations are also small in farm size. A large proportion of Thai farmers also own some paddy rice and upland areas.

Livestock in Plantation Systems

No statistics are available which detail the number of animals under the various plantation crops. However, large numbers of cattle and goats are raised in southern Thailand (Table 1) and many of these are raised in plantations, especially coconuts.

In northern Thailand cattle and buffalo are also grazed under tea, coffee, fruit trees and forests (Falvey 1977). Animals are kept primarily for weed control and animal manure rather than for meat or milk production. Therefore livestock production is always of secondary importance. Inputs are minimal and animals graze crop residues and unimproved natural pasture under plantations. A list of the species commonly found in the plantations is given in Table 4.

Table 1. Plantation crops and cattle and goat numbers in Thailand.

	North	North-east	Central	East	South	Total
Plantation crops ('000 ha)						
Rubber	–	n.a.	–	162	1525	1687
Oil palms	–	–	–	–	105	105
Coconuts	–	–	–	–	188	188
Fruit trees	116	12	274	114	152	668
Cattle and goat number ('000)						
Cattle	1171	1786	1130	48	826	4969
Goats	–	–	n.a.	–	81	81

n.a.— data not available
Source: Anon. 1988a, b.

Table 2. Average farm size (ha/household) and percentage of each size category in southern Thailand.

	Coconut[a]		Oil palm[b]		Rubber[c]	
	Size	(%)	Size	(%)	Size	(%)
Small	2–5	80	3–5	15	2	60
Medium	–	–	30–50	28	2–4	25
Large	–	–	500	57	4	15

Sources: [a]Terakul and Ratanapruk 1988; [b]Pongmanawa 1989; [c]Panomthareerak 1987.

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Naturalised legume cover crops such as *Pueraria phaseoloides*, *Calopogonium mucunoides* and *Centrosema pubescens* are sometimes present in pastures. The carrying capacity on native pasture varies with shading and fertility but is usually in the range of 1-2 ha per animal.

Table 3. Production statistics and export value of major plantation crops in 1988.

Crop	Production ('000 tons)	Farm value (million Baht)	Export value (million Baht)
Coconut	1 311	2 715	–
Oil palm	728	1 406	5
Rubber	851	15 462	23 328
Kapok	49	253	212

Source: Anon, 1988a.

Table 4. Naturally occurring forage plants in the plantations of Thailand (Manidool 1985).

Species	Environmental conditions
Arundinaria pusilla	Slightly shaded, light soils, moderate rainfall. Northeast.
Axonopus affinis	Moderately shaded, light to heavy soils, high rainfall.
Chrysopogon orientalis	Slightly shaded, sandy coastal soils, high rainfall. Southern area.
Coerhorachis glandulosa	Slightly shaded, light soils, moderate rainfall. Northeast.
Cyrtococum sp.	Moderately shaded, light soils, high rainfall.
Desmodium ovalifolium	Densely shaded, light soils, high rainfall. Southern area.
Heteropogon contortus	Slightly shaded, moderate rainfall, light to heavy soils. North and west.
Imperata cylindrica	Slightly shaded, upland soils all over the country.
Microstegium ciliatum	Densely shaded, very high rainfall, light soils. Southern area.
Ottochloa nodosa	Densely shaded, light soils, high rainfall. Southern areas.
Oplismenus burmanni	Densely shaded, light soils, high rainfall. Southern and eastern areas.
Paspalum conjugatum	Slightly shaded, moderately high rainfall, light soils, all over the country.
Rottboellia exaltata	Slightly shaded, light soils, moderately high rainfall.
Setaria verticelata	Slightly shaded, light to moderately heavy soils, high rainfall.

The use of improved pasture species and good management can raise animal production drastically. For example, one dairy farmer at Pakchong grew one ha of guinea grass (*Panicum maximum*) between rows of mango trees. He applied 125 kg/ha of urea and cut the grass every 30–40 days. This produced enough feed for eight dairy cows which produced an average of 10–12 L milk/day. The returns from milk alone were approximately 500 Baht/day.

The success of livestock–plantation systems often depends on the prospects for marketing. The major reason for the success of dairying is the government Dairy Promotion Scheme. This is in contrast to the often low farm-gate price for beef which, in turn, results in little interest by farmers in pasture improvement.

Potential and Prospects for Forage Integration

The success of forage–livestock integration depends on government policy, socio-economic factors, type of plantation, pasture species, ease of utilisation, type of livestock and marketing system.

Government policy

The government has indicated strong support for the development of dairy and beef industries in the country. Currently, only 13% of the total raw milk demand is produced in the country. The government plans to increase the number of dairy cows to 200 000. The production of beef and draft animals is also promoted.

Economic considerations

Plantation crops are likely to influence the prospects for livestock integration as the income from the different types of plantation crop varies greatly (Table 5). The return from coconut and kapok plantations is low and coconut and kapok farmers need to increase their income through intercropping with field crops or pastures. Farmers growing other higher value plantation crops such as fruit trees, rubber and oil palms may not be willing to integrate livestock since the main incentive is clearly to take care of the plantation crop.

Table 5. Yield and income from various plantation crops.

Plantation	Income/ha (Baht)	Yield (kg/ha)
Rubber	11 065	609
Oil palm	20 325	10 531
Kapok	7 217	1 144
Coconut	8 184	3 950
Mango	34 688	3 438
Cashew nut	32 635	1 625
Tamarind	112 500	1 250
Longan	67 250	3 363

Source: Anon. 1988, Rawanghet 1989.

Plantation type

Another factor affecting prospects for integration of forages is the type of plantation crop as this determines light transmission and competition. Coconut is probably the most suitable plantation crop. More than 50% of coconut plantations in Thailand are mature (>25 years old) and light transmission is high. Intercropping with forage crops can help in recovering the cost of replanting or of new plantings by providing income from otherwise unprofitable land. The total productivity of the area of mature coconut is increased and security is provided against the risk of low copra prices.

In rubber plantations, the highest potential for integration of forage crops occurs during the first three years. After this period, the growth of pasture species is increasingly restricted by decreasing light intensity. This also applies to oil palm. However, rubber and oil palm are high-value crops and the owner may not accept integration for fear of a possible reduction in yield of the main crop and the extra labour requirements.

Integration potential also exists in mango, kapok, tamarind and cashew plantations. The wide spacing of these plantations (8 x 8 m) allows light penetration to the ground.

Pasture species

Most pasture research on improved pasture under plantations has been conducted with coconuts. Boonklinkajorn (1978) reported that guinea and signal grass (*Brachiaria decumbens*) performed well on a poor soil under a coconut plantation when utilised in a cut-and-carry system. On a more fertile soil, para grass (*Brachiaria mutica*) grew well and competed successfully with weeds. The average yields of these three species were 58, 51 and 41 t/ha of fresh material for guinea, signal and para grass respectively. In coastal areas with poor soils and a lower light transmission, cori grass (*Brachiaria miliiformis*) showed good adaptation and was responsive to fertilizer. In older coconut plantations, ruzi grass (*Brachiaria ruziziensis*) grew well on both medium and fertile soils. Recently, the Department of Livestock Development reported a species comparison TRIAL under coconut and rubber plantations at Narathivat. Of the nine grass species, *B. miliiformis* and *B. humidicola* gave the highest yield under 31% of full sunlight (Egara et al. 1989).

Little research has been carried out under other plantations. Jewtrakul (1989) reported that a number of grass species can be intercropped with young rubber (Table 6). Yield of these species decreased gradually with increasing growth of the rubber. Jewtrakul also stressed that star grass (*Cynodon plectostachyus*) should not be intercropped with rubber since it has aggressive growth characteristics.

Table 6. Yield of pasture species under 2-5-year-old rubber.

Species	Dry matter yield (kg/ha) Years after rubber planting			
	2	3	4	5
Para	1 260	4 910	130	0
Ruzi	710	8 380	3 710	1 010
Signal	2 200	19 820	6 540	2 340
Guinea	1 710	11 494	4 960	1 240
Hamil	1 880	13 690	4 110	640
Green panic	310	6 850	1 640	440
Napier	4 580	13 330	2 660	520
Setaria	2 080	8 840	2 330	580
Guatamala	1 900	9 260	4 030	1 310

Source: Jewtrakul 1989.

Buranatham et al. (1989) reported that guinea grass mixed with *Centrosema pubescens* cannot be recommended for intercropping since this mixture restricted the growth of rubber significantly.

Data on forage production under fruit trees and forests are scarce. Manidool (1986) reported that under 10-year-old tamarind trees, ruzi, hamil and siratro (*Macroptilium atropurpureum*) produced good yields. In a mango orchard (8 × 8 m spacing) at Pakchong, 230 km northeast of Bangkok, guinea and ruzi grew well between the rows of mangoes when cut close to ground level for 2–3 years. Verano stylo (*Stylosanthes hamata*), guinea, hamil and ruzi grass grew well in a two-year-old *Eucalyptus* plantation (Manidool 1985).

While the technology for pasture species is ready for plantation crops such as coconut and rubber, the long-term effect of pasture species on plantation crops has not yet been determined.

Utilisation

The cut-and-carry system is suitable for all plantation crops particularly when the plantation trees are young. Jewtrakul (1989) suggested that grazing rubber is not practical because of the high risk of crop damage and interference with latex collection cups.

Grazing of cattle under coconut is common in Thailand. Boonklinkajorn et al. (1982) reported that 1.5 head/ha was an optimal stocking rate for signal–centro swards under mature coconuts, and was twice the stocking rate achieved on native pastures.

Type of livestock

The integration of dairy cattle with oil palm or rubber plantations is not practical since forage produces a high yield for the first few years only. Other plantation crops such as coconut, mango, cashew, and tamarind are more suitable for beef and dairy cattle.

Marketing

One of the most serious problems in beef production is marketing as there is no premium for quality. The marketing system favours the production of cheap meat from draught animals. High-grade beef fetches a good price only in the city. On the other hand, the relatively high, guaranteed price of milk represents a real attraction and provides considerable confidence to the farmers.

Constraints and Recommendations

One of the most important constraints is the lack of an adequate seed supply of promising grass and legume species. It is estimated that at least 1257 t of pasture seed are needed to meet the demand for sowing in 1990, and local supply can only satisfy 40% of the demand (Manidool and Leeratanachai 1990).

A further factor is the attitude of farmers. The plantation crop is the main source of income and the raising of animals is secondary to the needs of the plantation. The long period before a farmer sees a return on his investment in animals is also a disincentive. On the other hand, the return of investment in cash crops may only take 2–3 months. Furthermore, the required investment in animals is high when compared to crops. As labour inputs are already high for plantation crops the husbandry of animals may create a labour shortage.

Conclusions

The integration of pasture for livestock under plantations has considerable prospects. However, the possibility of conflicting management requirements and especially the extra labour required needs to be carefully considered.

The desired forage species must be highly shade-tolerant and should not be excessively competitive with the main crop. Cut-and-carry appears to be an appropriate utilisation system for rubber, while grazing is preferable for coconuts. Little experience with pasture and livestock integration under oil palm is available. More detailed investigations of species adaptation and appropriate management systems are urgently required if successful farmers' adoption is to be expected.

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Prospects for Improving Forage Supply in Coconut Plantations of the South Pacific

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Abstract

This paper analyses the reasons for success or failure of forages and cattle under coconuts and discusses the future potential for improvement of forages under coconuts within the physical and socio-economic environment of the South Pacific.

The South Pacific Region

THE countries and people of the South Pacific have many unique characteristics which separate them from the Asian region with which often they are erroneously grouped.

South Pacific countries have small populations in relation to land area and are isolated geographically from the rest of the world and from each other. In many cases, populations are isolated even within a country due to the fragmented nature of the multi-island states and, in the case of the Western Pacific countries, due to the rugged terrain of their volcanic islands. These countries are highly dependent on agriculture but their characteristics impede agricultural development because of difficulties in transportation, communication and marketing of produce.

The South Pacific countries (Table 1) are located between the latitudinal range of 5°N to 23°S; they support a population of about 5 million, occupy around 545 000 km^2 and are spread over approximately 1200 islands (Crocombe 1987).

This paper briefly describes the salient environmental features which impact on the ruminant industries of the region. The objective of the paper is to identify the present role and future potential for improvement of forages under coconuts within the physical and socio-economic environment of the South Pacific.

Geology and soils

The South Pacific countries span the zone of interaction between the Indian and Pacific tectonic plates. Both historical and recent volcanic and earthquake activity have contributed to present landforms and geologic features from which the soils of the region have been derived (Ward and Proctor 1980). Common soils are those formed on uplifted coral reefs, but sometimes improved with deposits of volcanic ash. It is on these soils that the majority of coconut plantations can be found. Soils formed on the older volcanic deposits are often steep and eroded or highly weathered, and therefore of limited fertility. Recent volcanic activity gives rise to very fertile soils such as occur on the southern Vanuatu island of Tanna. Fertile alluvial soils may be found on river deltas such as the Guadalcanal Plains in Solomon Islands and on Viti Levu and Vanua Levu in Fiji.

Steep dissected mountains of volcanic, metamorphic and sedimentary materials form the spine of Papua New Guinea, Solomon Islands and most Western Pacific countries, and render a large proportion of the land mass unsuitable for agriculture (Ward and Proctor 1980). No coconuts are grown in these areas.

Climate

Temperature maxima and minima at coastal stations at low latitudes average 32–29°C in January and 29–23° in July (Ward and Proctor 1980). Coconut plantations are generally found at or near sea-level. Pasture production clearly will not be limited by temperature in these areas, but rainfall is generally the more significant climatic influence due to orographic and rainshadow effects. Extremely high rainfalls of 4500 mm/year occur on the southern flanks of the central mountains of Papua New Guinea and Solomon Islands. In rainshadow areas, mainly on the north-western side of the islands, precipitation may be as low as 1200 mm/year, with water deficit occurring between the months of May and October. In wetter areas, heavy cloud cover significantly reduces radiation and pasture growth.

Agriculture

The countries of the South Pacific are still largely dependent on land and agriculture for employment, food supply, social cohesion and, more recently,

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export earnings. Islanders were originally subsistence gardeners cultivating coconut and various root crops which formed their staple foods. Following European and Asian settlement during the 1900s, there was alienation of significant areas of land to foreign-controlled estates initially for copra production. These larger estates led the way toward commercialisation of agriculture and, in many cases, export of commodities such as copra, palm oil, sugar, cocoa, coffee and fruits. Traditionally, livestock production has been based on the subsistence husbandry of pigs and chickens. While there is no tradition of ruminant animal production (except by Fijian Indians) there are now substantial numbers of ruminants in Pacific countries (Table 1).

Ruminant production is now promoted by all governments of the region, with the aim of promoting import substitution, improving the nutritional status of rural populations, and providing farmers with cash income (Bilong 1986).

Table 1. Ruminant livestock numbers in some countries of the South Pacific.

	Cattle	Buffalo	Goats	Sheep
Cook Islands	200	–	3 000	–
Fiji	159 000	–	59 000	–
Kiribati	–	–	–	–
Solomon Islands	23 000	–	2 000	–
Tonga	8 000	–	11 000	–
Vanuatu	103 000	–	12 000	–
New Caledonia	122 000	–	19 000	3 000
Western Samoa	27 000	–	900	–
Papua New Guinea	123 000	1 500	17 000	2 000

Sources: Ward and Proctor 1980, FAO Yearbook 1987.

Forages, Cattle and Coconuts

Cattle

The total number of cattle in the Pacific Island countries is approximately 565 000 head; Fiji (159 000), Papua New Guinea (123 000) and Vanuatu (103 500) have the largest populations (Table 1).

The first cattle, mainly dairy breeds, were introduced into the South Pacific region by missionaries in the late 19th century. Subsequently, cattle became important for weed control in coconut plantations managed by expatriates. World War II had a devastating effect on cattle numbers, particularly in Papua New Guinea and Solomon Islands, but numbers began to increase rapidly in these countries during the 1960s and 1970s with promotion and funding from local governments and international agencies (Shelton et al. 1986).

Assistance was given in two forms, firstly by establishing government-controlled nucleus cattle ranches, and secondly by promoting the ownership of cattle among indigenous smallholders. Smallholders were assisted with cheap credit, training, subsidies for fencing and pasture improvement, and with supervision by enthusiastic expatriate cattle extension officers. In Vanuatu, there was also a number of cattle ranches run by expatriates, while in Fiji large numbers of cattle were kept for draught purposes by Indian cane-farmers.

Approximately one-third of the total cattle population in the Pacific Islands is owned by smallholders. Almost everywhere, actual cattle numbers are much fewer than the projected numbers which were expected to result from various development schemes in the 1970s. This can be attributed to a number of factors.

- Indigenous smallholders had no prior experience with cattle, with the result that their standards of animal husbandry were lower than expected.
- Smallholders were encouraged to take part in commercial cattle production too quickly, and on too large a scale. There was no opportunity for the industry to evolve and consolidate.
- Many projects were located at a great distance from potential markets, and sometimes on islands remote from abattoirs.
- It was difficult for buyers to achieve a regular supply of adequate numbers of cattle, since smallholders tended to have many small herds in inaccessible areas.
- Brahman cattle obtained from government ranches were sometimes wild and difficult to control.
- Social status was attached to the ownership of cattle, and farmers were sometimes reluctant to sell (i.e. they were not commercially oriented).
- Disputes over the ownership of customary land interfered with management.
- Some smallholders encountered serious soil nutrient deficiencies which affected both pasture growth and animal nutrition.
- There was a significant slaughter, which finally had to be limited by legislation, of breeding cows.

As a result, some smallholder projects were abandoned and many had loan repayment difficulties. Projects were poorly managed and overstocked, resulting in loss of improved pasture species and serious weed infestation (Shelton et al. 1986).

Coconuts

The importance of the coconut in the Pacific Islands can hardly be overemphasised. Its significance to village people, particularly in atolls and outer island situations, is unlikely to change rapidly. The coconuts provide smallholders with a regular income which, while not a living, is a useful supplement to other sources of family income. However, unless productivity is improved on estates and plantation-mode smallholdings, its competitiveness with other crops will diminish even more (Ward and Proctor 1980).

Many coconut plantations are now old and past their most productive phase with little replanting of higher-yielding hybrids under way. Ageing coconuts are, however, very suitable for interplanting either with other cash crops such as cocoa and coffee or with forages for cattle production. Supplementary activities such as these are important not only to increase family income but also to offset fluctuations in copra prices. For these reasons, grazing of land under coconuts will become an increasingly important activity in the South Pacific.

Forages under coconuts

The major grazing resource in the Pacific region is natural forage under the ubiquitous coconut plantations. Cattle ownership by smallholders is largely under coconuts (especially in Solomon Islands, Vanuatu and Western Samoa), therefore programs designed to assist smallholders must direct their attention to this sector. Special advantages of the coconut–cattle system are the contribution of cattle to weed control, the lower pasture establishment costs (no land clearing) and the availability of cash from copra sales which offsets the cost of setting up a small livestock enterprise (Shelton et al. 1986).

Historically, establishment and management of productive improved forages under coconuts have not been given high priority by cattle owners in the region. Managers of the large plantations in Solomon Islands and Vanuatu viewed cattle primarily for grass control under coconuts. Little attention was given to improved methods of husbandry or pasture improvement. Similarly, smallholders were constrained by a range of economic, social, marketing and expertise limitations and had neither the will nor the resources seriously to consider pasture improvement (Shelton et al. 1986).

Government and aid donors, on the other hand, gave priority to pasture improvement, and supported substantial research programs in Papua New Guinea, Solomon Islands, Fiji and Western Samoa. Unfortunately, adoption of pasture technology by primary producers has been disappointing. The livestock industries in many countries currently are being consolidated, and increasing awareness of the importance of improved animal management, feeding and marketing will mean greater interest in pasture improvement in future. Currently, the major problem in the Pacific is the low level of adoption rather than an inadequate research effort (Shelton et al. 1986).

Prospects for Increased Use of Forages under Coconuts

From the foregoing discussion it can be seen that, historically, both cattle and coconut industries in the South Pacific have suffered from uneven development with a number of constraints hindering progress. It is also clear that the two industries must be better integrated to make profitable use of their inherent complementarity.

An analysis is now given of the future prospects for improving forages in coconut plantations using as examples the contrasting experiences of Solomon Islands and Vanuatu. Beef production is languishing in Solomon Islands with cattle numbers down from a high of 23 000 to around 8000 currently, and abattoirs unable to meet local demand for meat. In contrast, Vanuatu cattle numbers are rising, albeit slowly, the number of commercial producers is increasing, a small export industry of 1000 t meat/year is flourishing and confidence is rising.

There are similarities and differences between these two countries which may help explain these apparently opposite outcomes. These are now discussed in relation to the prospects for introducing forages into coconut plantations.

Availability of appropriate technology

Both countries have received assistance from the same Australian institution with the development of appropriate pasture improvement technology under coconuts. The University of Queensland and private consulting companies, with support from Australian aid funds, conducted research into pasture improvement in Solomon Islands from 1973 to 1982, in Vanuatu in 1985, and then from 1988 to the present time. The thrust of the research was similar in both cases as work was directed primarily to finding new species for shaded environments, developing methods of pasture establishment, understanding soil fertility limitations to pasture growth, the identification and control of weed species, and the production and management of grazing animals. In both cases, the work was well publicised in pasture handbooks (Steel et al., 1980; Macfarlane and Shelton 1986).

Both countries suffer from a small number of nationals adequately trained in forage improvement, as well as in other areas of the cattle industry. Scholarships for overseas study have been provided to address this issue but limited local expertise remains a problem.

Some differences in approach and in the situation at the commencement of the programs can be identified. In Solomon Islands, pasture research staff had no formal extension roles and were structurally and physically separated from the authority responsible for development of the cattle industry. This meant that there was little interaction between research and extension workers and producers. In Vanuatu, research and extension efforts are well integrated and pasture agronomists have regular contact with producers creating a three-way flow of information which appears to have promoted both understanding of local production systems and rates of adoption of new technology. Both large estate managers and smallholders show keen interest in pasture improvement.

There are other differences. Pasture research workers in Vanuatu benefited from and built upon Solomon Islands experience. They brought with them an understanding of humid tropical natural ecosystems, soil fertility constraints and weed control measures. They were also surprised to find that a well adapted and extremely robust grass was already in use under coconuts. Buffalo couch (*Stenotaphrum secundatum*) was first widely planted 30–50 years ago in both estate and smallholder plantations. Its success is due to shade tolerance, its wide adaptation to the various soil types, a prostrate habit making it suitable for growing under coconuts, and a vigorous stoloniferous growth characteristic which ensures that it forms a relatively weed-free sward, even under heavy grazing. In view of the wide variety of weeds (e.g. *Cassia tora*) found under coconuts, this last characteristic is of great importance.

The productivity and quality of buffalo couch was originally thought to be too low to fatten animals (Macfarlane and Shelton 1986). However, recent evidence from Vanuatu indicates that when it can be combined with naturalised high-quality legumes such as *Desmodium canum* and *Vigna hosei*, excellent liveweight gains can be obtained (B. Mullen, pers. comm.). More work is required to test the suitability of alternative persistent legumes such as the tree legume *Leucaena leucocephala*, the herbaceous legume *Desmodium heterophyllum* and the stoloniferous and rhizomatous accessions of the *Arachis* genus, for combining with buffalo grass. Moreover, other grazing-tolerant grasses are required to provide plantation managers with greater flexibility of choice of forage species for planting in different situations.

Social and cultural values of cattle owners

Some sociologists are concerned with the principle of introducing ruminants into the Pacific (R. Crocombe, pers. comm.). They argue that while there is a long history and tradition of pig production in the Pacific, there is no tradition of or familiarity with ruminants. This factor is given as the main reason for the failure of many livestock projects in the Pacific.

Solomon Islands and Vanuatu have differing histories in this respect. Dairy cattle were first introduced into Vanuatu in 1845 to provide milk to the missions and since that time there have been continuing introductions from Australia and France of a variety of dairy and beef breeds (Weightman 1989). The consequence was a numerous and diversified cattle herd and greater familiarity of the indigenous people with cattle management.

Currently, in Vanuatu, there is even a partial replacement of pigs by cattle in rural society on those islands where commercial opportunities exist. Several advantages of cattle over pigs were identified. Cattle are viewed as requiring less management than pigs, fit readily into existing coconut plantations, can be converted into cash when desired and are a very suitable source of meat for feasts at traditional ceremonial and custom occasions (J. Kamphorst pers. comm.). The adoption of cattle by rural society has not occurred to the same extent in Solomon Islands.

Another difference between the two countries is in the attitudes of the managers of the larger foreign-owned coconut estates. In Vanuatu, there is a greater consciousness of the role of cattle as a source of additional income while in Solomon Islands, cattle have been primarily used for brush control.

The differences outlined in this section can be related to historical differences but also to different current marketing opportunities. This latter aspect is discussed later.

Animal husbandry

The standards of management of cattle under plantations in the Pacific have been poor and characterised by general neglect.

In the smallholder sector there were often no stockyards; no selection, castration of bulls or culling of unproductive animals and therefore no control of breeding; no separation of different classes of stock, and no sub-division fences; and no permanent stock water supply or pasture improvement. Under these conditions, it is impossible to have animals in good condition for slaughter (Weightman 1989).

In the estate sector, although plantations were subdivided into a number of paddocks, the strategy was directed at improving coconut collection. Cattle were moved ahead of coconut gatherers and grazed at very high stocking rates to clear and trample grass and weeds as much as possible.

Programs directed at improving the standards of animal husbandry in both Solomon Islands and Vanuatu have been supported by foreign aid from Australia and British development assistance sources, respectively. These programs appear to have been more effective in Vanuatu where the extension activities of the Department of Agriculture, and in particular its Livestock Service, have significantly raised the standards of cattle and pasture management in both smallholder and larger plantation sectors (Weightman 1989).

Land tenure

There are many diverse systems of tenure of land in the Pacific although most were originally devised to suit the needs of subsistence agriculture rather than those of commercial agricultural production (Crocombe 1987). The situation was complicated between 1850 and 1900 when European settlement alienated substantial areas of land. Currently, most countries have introduced land reform measures in an attempt to meet the needs of modern agricultural production. Vanuatu, while still struggling with the problems of land reform, has developed a successful system of long-term leases for expatriates wishing to farm previously alienated plantations. In some cases, leases were granted while the issue of land ownership was still being investigated.

The overall result of this enlightened approach is that Vanuatu has a core of innovative expatriate plantation and estate cattle managers who, in the past, have provided the majority of cattle for slaughter in abattoirs. This has ensured a relatively reliable supply of slaughter animals and ensured the early viability of the industry. In the meantime, Ni-Vanuatu managers have slowly improved their expertise and their contribution to the commercial viability of the industry. Ultimately it is expected that the majority of animals for slaughter will come from Ni-Vanuatu properties.

Marketing

The commercial marketing of livestock in the Pacific Islands is limited by a number of difficulties. Animals are spread in small numbers over many islands, so that transport to abattoirs requires a complex infrastructure of buyers, holding yards and inter-island barge transport. Effective systems are few, and usually depend on foreign aid.

Most Pacific countries have abattoirs. However, these are necessarily near major population centres, and it is difficult for smallholders from outlying islands to gain access to them, even though prices offered at abattoirs are generally higher than those obtained locally. Consequently, abattoirs are usually underutilised and barely profitable while many animals are slaughtered using bush slaughter methods. Increased commercial ruminant production by smallholders, coupled with improved marketing methods, would improve the efficiency and profitability of abattoirs.

Again Vanuatu has had greatest success in overcoming the limitations outlined above. The Livestock Service has worked hard and successfully to encourage the participation of smallholders in the commercial industry. This has been achieved by provision of animal collection points and barges to outlying islands and remote areas to encourage sale of store animals for fattening on better quality pastures close to abattoirs. In this way, structural integration of the industry is being achieved. An integral aspect of this marketing strategy is a system of graded payments providing financial incentive for young, properly finished animals.

A recent development in Vanuatu is private small-scale cattle collection and transportation on the island of Santo. Small trucks and cattle-crates supplied by private entrepreneurs, but encouraged by judicious government assistance, ensure that smallholders get their animals to market.

Conclusions and Future Directions

Cattle numbers have increased dramatically in the Pacific region this century. Over the past 20 years indigenous smallholders have become increasingly involved, but with variable success. Significant pasture research has been carried out, but the level of successful adoption of permanent improved pastures remains disappointingly low, although awareness of the importance of improved pastures to animal productivity is increasing. The outlook for the cattle industries is relatively optimistic, with the possible exception of Solomon Islands, and governments are proceeding with plans for further inputs to the industry to achieve self-sufficiency and, in some cases, develop export markets. As the Pacific economies improve, demand for beef can be expected to increase.

There is a need for assistance and progress in several sectors of the industry, to ensure that the incentive for pasture improvement is not limited by other factors. For instance, herd management and cattle husbandry, marketing infrastructure and credit facilities are often limiting and should receive appropriate attention. Without such balanced development farmers cannot be expected to adopt improved forages.

It is clear from experiences to date that future research should aim to provide simple and robust systems suitable for indigenous smallholders with only recent experience of pasture and cattle management. Systems such as those developed with *Stenotaphrum secundatum* in Vanuatu should be tested more widely in the region. There is a need to collate and integrate all existing, often fragmented information on species performance and soil fertility data for the benefit of all countries in the region. Species introduction and evaluation and soil fertility testing will continue to be research priorities, as management of poorer soils is likely to involve choice of adapted species rather than fertilizer addition, at least in the short term. Further investigation of the utilisation of naturalised legumes such as *Leucaena leucocephala* and *Desmodium heterophyllum* and new legumes such as *Arachis* species should be given priority because of their demonstrated productivity and persistence in shaded environments.

The problem of poor adoption of improved pastures by primary producers must be faced. Research workers must work more closely with extension officers and innovative farmers to ensure that research emphases are realistic and that extension recommendations are practical and appropriate.

The low number of nationals in pasture agronomy and their lack of expertise are also serious limitations to further development. There is clearly justification for direct technical assistance to meet short-term needs and for training assistance to increase local competence. This may take the form of workshops, study tours, regional seminars or tertiary study. In this way the potential for greater integration of forages and cattle under coconuts may be realised.

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Forages for Plantation Crops in Sri Lanka

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Abstract

The greatest potential for integration of animals and plantation crops in Sri Lanka exists in young rubber and mature coconut plantations. Despite experimental evidence of the suitability of improved pasture species for integration into these plantation areas, only a small proportion of the land available for forage production has so far been planted to improved species. Major constraints for forage development are low income from dairying compared with cash crops, high initial capital investment, scarcity of land due to competition from other enterprises, slow rate of development of forage programs and seasonality of forage production in certain climatic zones. Strategies must be developed to improve forage–livestock production through strengthening research extension work and improving farmers' skills.

SRI LANKA has a population of 16.5 million and is a tropical island located between latitude 5° 55' N and 9° 51' N. Topographically, the island has a crown of mountains rising to 2000–2400 m in the south-central region which is surrounded on all sides by fairly flat lowlands. The three major agroclimatic zones are the wet zone (>1875 mm annual rainfall with highest falls during May to September), the intermediate zone (1500–2000 mm annual rainfall) and the dry zone (875-1875 mm annual rainfall). Major soil types are alfisols, ultisols, oxisols, histosols, vertisols and various entisols. Soil acidity is widespread in many parts of the country.

Of the total land area of 6.6 million ha, almost 1 million ha are under plantation crops. Tea plantations (222 000 ha) are grown up to an elevation of nearly 2300 m. Rubber plantations (200 000 ha) are situated mostly in the low country wet zone and are grown up to an elevation of 700 m. Coconut (416 000 ha) is the most widely cultivated plantation crop and is second only to the paddy crop area of 865 000 ha (Anon. 1989). Coconuts are grown up to an elevation of 1000 m in the low-country wet and intermediate zones and to some extent in the dry zone wherever facilities for irrigation exist.

Tea is the major export crop with an annual production of 227 million kg and export earnings of Rs 12 299 million (Anon. 1989). The tea industry is operated predominantly on an estate basis with more than 80% of estates more than 5 ha in size. Rubber is Sri Lanka's second-largest export earner with an annual production of 122 million kg and exports of 99 million t amounting to Rs 3706 million. Smallholders own about 70% of the rubber-growing land in the country. Coconut constitutes the third-largest export of Sri Lanka, although about 70% of the total coconut production is used for domestic consumption. Of the annual production of 1933 million nuts, only 224 million are exported with earnings of Rs 1538 million. The smallholdings comprise nearly 85% of the total coconut area. It has been estimated that nearly 70% of the coconut area of 200 000ha) has the potential for successful intercropping. Although coconuts thrive well in all parts of the low country, about 70% of the coconut area is concentrated in the 'Coconut Triangle' formed by districts of Colombo, Gampaha, Kurunegala and Puttalam where almost 40% of the indigenous cattle population is located.

Like many other developing countries, Sri Lanka is not self-sufficient in livestock production. In 1982, the ruminant population was approximately 1.7 million cattle, 0.9 million buffalo, 0.5 million goats and 0.03 million sheep (Anon. 1985). More than 70% of these animals are located in the lowland dry zone. National milk production is around 450 000 L/day, which supplies approximately half domestic consumption (Rajaguru 1986). The majority of dairy farmers are smallholders with 1–2 milking cows kept as a subsidiary occupation to supplement income. Milk production in smallholdings is based on cut-and-carry systems but productivity is relatively low as a result of poor management.

Natural grasslands occupy 4% of the total cultivable land of the island. However, other areas (e.g. coconut plantations) also contribute significantly to the available forage resources (Table 1). Of the 700 000 ha of forage resources, only 17 000 ha are planted to improved forage species. In fact, one of the main causes of low production of the local livestock

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herd is poor nutrition due to shortage of forage. If this shortage is to be overcome, a further 200 000 ha of improved forages need to be planted. Unfortunately, land development projects (e.g. Mahaweli Diversion Scheme) have removed some of the more fertile land previously available for forage production. In other instances, high-value crops with export potential have emerged, which has changed land-use patterns.

Table 1. Forage resources in Sri Lanka.

Farming system	Area (ha)
Non-irrigated highlands in the dry zone	325 000
Villu and similar lands in the dry zone	80 000
Coconut plantations	140 000
Marginal tea land in the mid-country	40 000
Hill country tea estates	4 500
Patna lands in the hill country	55 000
Herbage from paddy fields	30 000
Roadsides, etc.	5 500
Other areas forming part of mixed farming homestead systems in the wet zone	20 000
Total	700 000

Source: Siriwardena and Clarke (1986).

Forage Opportunities in Plantations

Tea

Opportunities for forage production in tea plantations are limited. Forages are used for soil amelioration during the replanting phase, for soil conservation between the tea bush rows and as shade trees for tea. It is established practice to rehabilitate old tea lands by planting either Guatemala grass (*Tripsacum laxum*) or Mana grass (*Cymbopogon confertiflorus*) for a period of 18 months to recondition the soil before replanting the area to tea (Sandanam et al. (1987). While these grasses are well suited for soil amelioration, they are of poor feed quality. The practice of growing leguminous covers such as *Crotolaria* spp., *Stylosanthes guianensis* or *Desmodium ovalifoluim* in the interrow spaces is beneficial for conserving soil. *Gliricidia sepium* serves as a valuable shade crop and green manure as well as for soil conservation. Trees are lopped prior to dry periods and spread over the soil to conserve moisture. While forages are used in tea plantations, their use and management is primarily directed at soil conservation and the requirements of the tea crop.

Rubber

It normally takes 6–7 years for new rubber plantings to attain the tappable girth of 50 cm. Unless intercropped in some manner, the land is unproductive and is an economic burden to the grower until tapping commences. The present method of avenue planting of rubber with wide row spacings (10 m) facilitates cropping of interrows until the developing rubber canopy at about four years of age begins seriously to limit production. Vacant patches in mature rubber plantations caused by loss of trees from White-root disease (*Rigidoporus lignosus*) constitute about 8% of the total land under rubber in Sri Lanka (Liyanage 1978), and forage cultivation in these patches would be possible. However, the smallness of these patches and their wide scatter in plantations suggests that fodders for cut-and-carry feeding rather than for grazing are more appropriate.

As much of the rubber is planted on steep slopes, annual cropping is often not possible. The creeping cover-crop legumes puero (*Pueraria phaseoloides*), centro (*Centrosema pubescens*), *Calopogonium* spp. and *Desmodium* spp. are widely used and these are also good forage crops. There is a need to integrate these with compatible grasses. Some investigations into the suitability of various forage grasses and legumes have been carried out by Waidyanatha et al. (1984), who reported results of a study of zero-grazed pasture over six years in immature rubber. The grasses *Panium maximum* (Guinea B), *Brachiaria brizantha* and *Brachiaria miliiformis* were planted alone or in mixtures with the two legumes puero and centro. Yield declined sharply as light transmission decreased, especially after the fourth year. Guinea B grown alone outyielded both *Brachiaria* species while *B. brizantha* yielded significantly more than *B. miliiformis* in the third and fifth years. Guinea B–puero was the outstanding mixture and it outyielded pure Guinea B as well as the Guinea B–centro mixture.

In another experiment, three grasses, Guinea B, *B. brizantha* and napier (*Pennisetum purpureum*) were cultivated alone or in combination with four legumes, puero, centro, and stylo (*Stylosanthes guianensis*) cv. Schofield and cv. Oxley. Of the mixtures, the highest yields were obtained from the two napier–stylo associations, but no mixture significantly outyielded the pure grass treatments. Legume component yields were much higher for the stylo cultivars than for puero or centro. The highest legume content was in the Schofield stylo–Guinea B association (33%) and the lowest in the puero–*Brachiaria* mixture (4%).

Dissanayake and Waidyanatha (1987) investigated the competitive effect of ten grasses and an uncut puero cover crop on the growth of young rubber trees. The average yield for all species was about 8 t/ha/year for the whole period, with Guinea A and Guinea B yielding the highest (10 t/ha/year) and Green panic (*Panicum maximum* cv. Petrie) yielding the lowest (6 t/ha/year). Both height and girth of trees were reduced when crops were planted 1.0 m away from trees compared with 1.5 m. With regard to tree height and girth, *B. brizantha*, *B. decumbens* and Guinea B were the most competitive whereas *Paspalum*, *Setaria*, Green panic and *B. miliiformis* were the least competitive. Guinea A, napier and *B. ruziziensis* were moderately competitive. It seems unlikely that competition is a major limitation when considering the economic feasibility of forage production under young rubber.

Coconut

The majority of coconut lands in the wet and intermediate zones is suitable for forage growth and already there are several species of native grass growing under these plantations. Most are weed species giving a low herbage yield of poor quality which supports only a low carrying capacity of around 0.4 cattle/ha. In 1955, the Coconut Research Institute of Sri Lanka pioneered research on improved forage production under coconut. Satisfactory pasture growth can be obtained under new plantings up to the fifth to eighth years and again from about 20 years onwards in mature stands spaced 7 m apart or more. The effect of the fertilised grasses *Brachiaria brizantha*, *B. miliiformis* and *Guinea B* on coconut yield was investigated by Santhirasegaram (1966a). *Brachiaria brizantha* and *B. miliiformis* gave a coconut yield increase of 235 and 545 nuts ha/year respectively, while Guinea B caused a reduction of 245 nuts/ha/year. Herbage yield of Guinea was twice as high as those of the two *Brachiaria* spp. and resulted in heavier competition for nutrients. In another experiment, a *B. brizantha* pasture reduced nut yields by 13% when manuring was not done (Santhirasegaram 1966b). Because of its shade tolerance and lower competitiveness, *B. miliiformis* has been recommended for coconut plantations since 1967. Fertilizers recommended for *B. miliiformis* are (in kg/ha) 50 N, 25 P and 50 K, applied in two split applications at the start of each monsoon (Appadurai 1969). For fodder grasses, half this dose has been recommended immediately after each cut. In addition, palms have to be manured separately with 3 kg of adult palm mixture fertilizer.

A number of new forage species has been introduced and *Brachiaria dictyoneura* produced 40% more herbage than *B. miliiformis* (Table 2). It also responded well to added nitrogen. Another desirable characteristic observed in B. dictyoneura was its high degree of drought tolerance. It was also more than 50% digestible. Some of the other promising species are green panic and *Panicum maximum* cv. Hamil for cut-and-carry systems. Pangola grass (*Digitaria decumbens*) is well suited to areas with a light transmission of more than 85%, particularly where sheep are reared. However, this grass is not very shade-tolerant and has not persisted in more shaded grazed pastures.

The beneficial effects of legumes in pastures have been well established. The main difficulty with legumes is their lack of persistence. Calopo (*Calopogonium mucunoides*) is sometimes used as a pioneer legume in mixtures with centro or puero to give early cover, but this legume has low palatability, is short-lived and has poor drought tolerance. Centro is deep rooted, has a high degree of drought tolerance, and is able to produce more than 10 t/ha/year of dry matter under coconuts. It also mixes well with *Brachiaria* spp. and is adapted to many soil types. It is readily accepted by ruminants. Puero grows on a wide range of soils but prefers heavy soils in the high rainfall areas. Apart from its forage value, it has served very effectively in the conservation of soil and moisture coconut lands with large additions of leaf litter amounting to 8–10 t/ha/year. Siratro (*Macroptilium atropurpureum* cv. Siratro), being deep-rooted, has good drought tolerance and is suited particularly to dry areas. It has produced around 10 t/ha/year of dry matter with satisfactory yields of leaf litter. It has mixed well with *Brachiaria* pastures, particularly *B. brizantha*, under coconuts. A problem with siratro is its low productivity and susceptibility to *Rhizoctonia* leaf rot in the wet and intermediate zones. The suitability of stylo and *Desmodium* spp. for coconut areas is still not conclusive and wider testing is needed.

Table 2. Productivity of various grasses grown for three years under coconuts at two levels of nitrogen.

Species	Yield (kg DM/ha/year) 26 kg/ha N	52 kg/ha N
Brachiaria miliiformis	7 611	7 920
Brachiaria brizantha	8 550	9 397
Brachiaria dictyoneura	10 392	11 317
Brachiaria ruziziensis	7 342	7 636
Digitaria decumbens	6 434	7 011
Panicum maximum cv. Petrie	655	7 744
Panicum maximum cv. Guinea B	7 119	7 997
Setaria sphacelata	7 407	8 862
Pusa giant NB 21	4 705	5 449

LSD ($P<0.01$) between species = 1045; LSD ($P<0.05$) between levels of N = 494.
Source: Ibrahim and Ferdinendez (1984).

The use of nitrogen-fixing trees as multipurpose trees in coconut plantations has received increasing attention in recent times. Several trials have been conducted to study their growth and yield performance and their specific uses under various management conditions. The most widely studied tree legumes are gliricidia (*Gliricidia sepium*) and leucaena (*Leucaena leucocephala*). Gliricidia and leucaena, planted 2.0 × 0.9 m in double rows in mature coconut plantations and lopped at three-monthly intervals, produced 7–10 t/ha and 12–16 t/ha green matter and 8–15 t/ha and 14–20 t/ha fresh firewood during the first and second years of planting at four sites in the Coconut Triangle (Liyanage and Jayasundera, 1987).

In the intermediate zone, an integrated farming system of 0.8 ha was established in a 45-year-old coconut stand, planted at 137 palms/ha (Liyanage et al. 1989). The area was divided into six paddocks. One served as a control, while the other five were planted with rows of leucaena and gliricidia (2500 trees/ha) and a mixture of *B. miliiformis* and puero. Along the boundary fence, leucaena and gliricidia were planted alternately 1 m apart. Coconuts in the control plot received (kg/tree/year) 0.8 urea, 0.6 superphosphate and 1.6 muriate of potash while those in the other five paddocks received 0.75 muriate of potash and 0.18 superphosphate. One year after planting, four 6-month-old Jersey × local cross-bred heifers were introduced to the experiment. A 30-day rotational grazing system was used in the five paddocks. In addition to the feed from the pasture, cattle were fed with gliricidia and leucaena leaf of up to 5 kg fresh leaf/head/day. During dry periods, urea-treated rice straw was fed at 4 kg/head/day (160 g urea/animal/day). Copra yields in the integrated system were similar to that of the control plot. Three years after establishment of the system there was no drop in critical nutrient levels in coconut leaves. It appeared that the total nitrogen requirement was met by the addition of urine and dung from the cattle. The actual nutrient returns from the dung and urine (kg/palm/year) amounted to 0.8 N, 0.1 P and 0.7 K.

In the control plot (monoculture system), a total expenditure of Rs 8.10/palm/year was made for inorganic fertilizers. In the integrated system, the nitrogen was provided by dung and urine, and only Rs 2.49/palm was spent on fertilizer. This clearly demonstrated that the integrated farming system resulted in a saving of 69% on the cost of inorganic fertilizer while increasing the productivity of the farming system. Average daily liveweight gain of the heifers was 306 g/head during the first year.

In another feeding trial, gliricidia leaves were fed with *B. miliiformis* at a ratio of 50:50 to Jersey × local heifers and produced daily liveweight gains of 700 g during the wet season (Liyanage and Wijeratne, 1987). Chadhokar and Lecamwasam (1982) also found that gliricidia could be used successfully as a high-protein supplement.

Constraints for Forage Development

Despite government assistance for forage development, only 17 000 ha are planted to improved forages. The area under plantation crops (particularly coconuts) which could be used for forage production is not fully utilised. The relatively slow progress is largely due to the following economic, social and technical constraints facing the growers (Liyanage 1989).

- Farmers produce very little of their own forage. They are reluctant to grow forage on their own land as their priority is for food and cash crops. Many farmers do not have their own land for cultivation.
- Competition from other enterprises, various land development projects, sudden changes in policies towards high-value crops with export potential results in the unavailability of land for forage production.
- The income from dairying in terms of land and capital invested is generally lower than that from crops.
- The task of changing the attitude of the farmer and promoting better forage management is a formidable one, as animals generally are a sideline to farming operations. Also, when forages are introduced, the paddy farmers expect the same growth rates obtained for paddy and when this is not evident, they lose interest.
- It cannot be tried out by the farmer on a small scale as can other crops.
- High initial capital investment is required (cows, sheds, etc.).
- Farmers have been heavily dependent on concentrate feeding which, with the escalation of feed prices, has become uneconomical.
- Slow progress in herbage development programs has resulted in the continuing use of low-quality forages. Many farmers who have planted improved forage under assistance schemes do not show sustained interest, and their plots show evidence of neglect.
- Planting materials (cuttings and seeds) are not readily available to the farmer. The current production of seeds is concentrated in the private sector and the level of production is largely determined by advance orders.
- Forage production is seasonal due to the bimodal rainfall pattern in the intermediate and dry zones. Forage conservation programs are insufficient. Silage preparation in pit silos has limitations for farm use. Haymaking is difficult as the time of surplus forage which would be available for conservation coincides with the period of high rainfall.
- Lack of strategic development centres and extension services. The links between researchers, extension workers and farmers have been poor.
- Capacity development for forage research has been inadequate.
- There has been a rapid diminution in the funding for research with the result that there is inadequate maintenance of research-related supporting services.

Future Research Priorities

The constraints identified above call for research on both biological and socio-economic aspects, and the development of an efficient extension service in order to make these forage production systems more productive, economically adaptable and successful. The following priority areas are suggested for future research.

- Improvement of pasture grasses, fodders and legumes through selection of varieties specifically adapted to the various climatic and soil conditions;
- further study of nutrient uptake and recycling in forage–plantation systems (particularly coconuts);
- further research into establishment, compatible mixtures and management techniques for forages;
- the agronomic requirements of nitrogen–fixing tree crops when they are grown in plantation crops need to be standardised, and the production of tree legumes in waste lands and fences should be promoted;
- research is needed on concentrate mixtures to address and alleviate deficiencies in forage quality;
- development of simple and economical methods of forage conservation is required; and
- active research on all aspects of integration needs to be initiated.
- It is of the utmost importance to realise that the prime objective of efforts should be to develop the skills of the farmer, rather than to concentrate on improving the farm. Concurrently, the links between the researcher, extension worker and the farmer need to be fortified.

Agricultural development in Sri Lanka has been moving from predominantly rainfed extensive cropping to intensive irrigated cropping, from monocropping to multiple cropping, and from pure cropping systems to integrated crop–livestock production systems. The future of the forage– livestock industry depends to a large extent on how successfully this subsector will be able to co-exist with the changes that are taking place in the entire agricultural sector.

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