POTENTIAL OF SILVOPASTORAL SYSTEMS IN THE RAIN FORESTS

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ABSTRACT

Grazing animals, mainly cattle and sheep are important components of the agricultural production systems in the rain forest areas. Dwarf sheep and goat are common in the humid zone of Africa, as a source of meat and income. Carabao (water buffaloe) and cattle are the main draft force in crop (mainly rice) production systems in Southeast Asia, where grazing under plantations for beef production is also common. Given the high cattle population and high levels of demand for beef and milk in tropical America, ranching for cattle production in the humid tropics has been expanding in the Brazilian Amazon and in Central America. Also small farmers after clearing the forest for crop production move into mixed farming systems incorporating cattle as a way of saving and income generation. The main problem of cattle ranching and mixed farming in the rain forest areas is the lack of sustainability of the production systems. Open pastures with the existing technology rapidly degrade increasing pressure for further deforestation.

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The paper discusses the possibilities and potential of integrated (tree-pasture) systems in the rain forests as means of developing sustainable production systems Examples of spontaneous low stocking silvopastoral (grazed tree plantations) systems occurring in Southeast Asia as well as experiences with multipurpose trees (fence-shade-crop-fodder) in tropical America are presented

Research results on the interaction between trees and pastures, trees and grazing animals in silvopastoral systems, and about the shade tolerance of grasses and legumes, are presented

The socioeconomic and biological constraints for the development of integrated silvopastoral systems are discussed Finally, suggestions for future research are presented

INTRODUCTION

Deforestation and environmental degradation, of major concern in the rain forests, are the result of logging, shifting cultivation, plantation agriculture, and cattle raising The initial boost in soil fertility following slash and burn is rapidly lost when original vegetation is not replaced by production systems capable of nutrient recycling Degradation, including run-off, leaching, and soil erosion, is the common feature of land use in the humid tropics when population pressures increase

Cattle raising is the predominant production system in the disturbed lands of the Central American rain forest and the Amazon Cattle in Southeast Asia are mostly used as draft animals in intensive agriculture In the humid belt of Africa, cattle are not important due to the disease tripanosomiasis, sheep and goats are the most common animals in the predominant shifting cultivation systems

The main forces inducing deforestation and degradation are of a socioeconomic nature The rain forests of Africa are cleared mostly for subsistence agriculture The Southeast Asian rain forests are also being cleared for subsistence agriculture and tree plantation development In Latin America, settlers, normally landless rural people, move into rain forest areas in an attempt to leave poverty behind Because of poor land resources and the ephemeral increase in soil fertility occurring after clearing and burning of the original biomass, farmers (settlers) often degrade the environment and then move to open more virgin forest or to abandon the area The abandoned degraded lands are sold to remaining successful settlers or to capital investors These second-hand farmers are the ones establishing pastures, and it is in this way that land is consolidated in medium- sized properties for cattle raising Examples of this occur in Caquetá, Colombia, Pucallpa, Peru, Guácimo-Guápiles, Costa Rica, and Azuero, Panama, in all of which dual-purpose cattle production systems (beef and milk) are being developed and integrated with crops and trees in varying proportions These semi-intensive Central American and Andean Amazonian integrated production systems are small to medium (20-300 ha) in size On the other hand, extensive, large-sized cattle ranching has developed in the Brazilian Amazon as a result of subsidies and incentives given by government to induce large enterprises to invest in the region (SUDAM, 1983) These fiscal incentives, initiated during the sixties, have fortunately now been stopped since the late seventies

Lack of appropriate technology for intensification of land use and conservation of natural resources, together with inadequate national development policies, are the main forces behind the ever increasing deforestation and degradation in Africa, Southeast Asia, and Latin America This ecosystem degradation and lack of sustainability of prevailing production systems is a major challenge for research

This review discusses the possibilities and potential of integrated silvopastoral systems for sustainable production in disturbed rain forest lands

THE ROLES OF SILVOPASTORAL SYSTEMS IN THE RAIN FORESTS

1 Production systems in relation to population density

To a large extent, population density is the major determining factor in the development of agricultural production systems In Figure 1, changes in management intensification of forest, of agriculture, and of animal production systems are shown in relation to human population intensity When low population density occurs, the predominant production systems are gathering and long-fallow shifting cultivation, together with incipient extensive ranching for beef production When road infrastructure is available, timber extraction may also occur Under intermediate population densities, an intensification of resource management occurs, with timber extraction moving into reforestation and forest management, while shifting cultivation is forced into shorter fallows multipurpose trees become important and beef production systems move into dual-purpose cattle production systems When high population densities occur, the original forest practically disappears, trees are mostly in plantations (industrial products and timber), and crop production systems, greatly expanded in area, become high-input specialized systems Under these conditions, dual-purpose cattle systems decrease in relevance, yielding to specialized milk production ones

This relation between intensification of land use and population density provides a perspective of the dynamics of the production systems Many areas of the humid tropics, depending on distance to markets and infrastructure, have different population densities at the microregional level (e g , around cities) This unevenness in population density determines the predominant production systems For example, in the Amazon of Brazil, in regions closer to cities such as Belém, Manaus, and Porto Velho, medium to high population densities occur As a result, beef cattle production systems are shifting into dual-purpose production, slash and burn agriculture is no longer feasible due to short fallows, and plantations and multipurpose trees are becoming important as virgin forest area is reduced Simultaneously, in more distant Amazon areas, population density is still very low and gathering of products (such as Brazil nuts) and rubber tapping, etc , occur along with extensive cattle ranching More than 85% of the Brazilian Amazon is still untouched, harboring native ethnic groups under very low population densities

Integration of trees, crops, and pastures is most likely to occur when intensification is spurred by higher population densities

2 Potential roles of trees

It is important to visualize the different roles of trees at two levels the farm level and the regional or global ecosystem level Farmers hardly ever adopt a technology for its potential contribution to the ecosystem level New technologies based on the use of trees and pastures must be made attractive to farmers for their contribution to potential profit and management objectives On the other hand, awareness by decision-makers of potential benefits at regional levels should lead to policies fostering the adoption of silvopastoral systems

Roles at farm level

At the farm level, the potential roles of trees in silvopastoral systems are

Living fence Fencing in semi-intensive and intensive production systems is extremely important, and its establishment and maintenance are expensive By reducing maintenance costs, living fences could be adoptable by farmers

Forage The role of forage trees in rain forest areas with no or reduced dry seasons is of little importance However, the humid tropics include large areas with a definite three- to four-month dry season During these periods, farmers may face shortages of high-quality feed The possibility of utilizing tree foliage to supplement feeding and grazing during these dry periods may be important for farmers *Leucaena*, *Gliricidia*, and *Erythrina* are some known possibilities for areas with higher fertility soils

Shade In the process of intensification of cattle production, the systems shift from beef ranching into more intensive dual-purpose ones This shift occurs together with increases in European blood in crossbred animals in order to increase milk production potential These more efficient animals will require lower temperatures in the paddock area Thus, trees providing shade for this type of animal might be an essential component

Nitrogen fixation Nitrogen and phosphorus, in the predominantly acid soils of the humid tropics, are the most important nutrients for sustainability of production systems As inorganic sources are expensive, efficient N-fixing herbaceous and tree legumes could be adopted

Income In addition, the benefits of trees and pastures in these systems should be measurable in economic terms Technologies contributing to savings in the use of inputs, increased productivity of land and animals, and reduced maintenance costs of the system are the ones to be adopted Timber, industrial and fruit trees are very important to generate additional income in these systems

Roles at the regional-global (ecosystem) level

As mentioned earlier, important benefits of the integration of trees and pastures may not be directly relevant to farmers However, they are extremely important for the conservation of land resources and the environment as a whole Politicians and decision-makers at the national and international level should be fullv aware of these potential roles

Soil conservation Utilizing deep-rooted adapted trees in association with high cover pastures effective in recycling nutrients can play the important role of preventing soil erosion in hilly areas in the humid tropics However, when slopes are steepest and in watershed areas, reforestation is probably the best alternative

Water regulation Trees and pastures can contribute to reduction in run-off by improving vegetation cover, as well as structure and permeability of soils, through profuse and deep rooting These improved covers will also contribute to higher evapotranspiration, thus improving the hydrologic balance in the ecosystem and thereby minimizing waterlogging and flooding in the lower parts of the watershed, as well as tapping water and nutrients from deep in the soil profile during the dry season

Capture of CO_2 At the global level, the greenhouse effect is an important consideration for planting trees in association with pastures in the humid regions of the world Higher biomass vegetation will capture CO_2, thus compensating for imbalances caused by the release of CO_2 into the atmosphere under deforestation

Albedo The color and reflective power (the fraction of the incident light of the electromagnetic radiation that is reflected by the surface of plants) of vegetation is different depending on the predominant species in the biomass Open grass pastures tend to be yellow-green, when N fixing herbaceous and tree legumes are included, the albedo of the pasture becomes more blue-green, improving its capacity to capture solar energy and heat This will greatly contribute to a better balance of air temperature at the ecosystem level

Economic growth If trees and pastures are effectively contributing to farmers' income, the ensuing diversification in economic growth could increase regional sustainability Regional wealth will trigger the development of infrastructure and a better standard of living for the society

SOME EXAMPLES OF SPONTANEOUS SILVOPASTORAL SYSTEMS

On Hainan Island, China, rubber plantations are grazed *Othocloa nodosa* is the predominant grass which grows native under the trees Grazing is done to produce beef as a plantation byproduct, and manure is also moved close to the trees manually to replace chemical fertilization On Malaysian rubber plantations, families of laborers, mainly Indian in origin, own crossbred cattle These cattle utilize the native grassland (mostly *Axonopus* spp and *Paspalum* spp) growing under the trees in the plantation for milk production Grazing is supplemented with cut-and-carry Elephant grass (*Pennisetum purpureum*) Grazers return faeces into the forage crops systems Also in Malaysia, young rubber plantations are grazed by sheep, to assist with weed control and to obtain extra income from mutton In Chumphong, Thailand, coconut plantations are also grazed by cattle to utilize the native grasslands that spontaneously occur These grasslands, mostly made up of *Axonopus compressus* and *Paspalum conjugatum*, are utilized to produce beef, as extra income to small- to medium-sized copra farmers

Production systems in Latin America are different and integration is less obvious However, some interesting cases also occur In Napo, Ecuador, small-sized farming systems include coffee and subsistence crops in shifting cultivation and pastures based on *Brachiaria humidicola* to reduce the need for labor in weed control Cattle are used for beef production and as a savings mechanism in an inflationary economy In Rio Branco, Acre, Brazil, in predominant Alfisols, Brazil nut (Castaña du Pará) is a native tree present in the original forest When clearing the area, farmers protect these trees from clearing and burning, establishing crop and pastures around the trees In this way, a valuable tree crop contributes to the economy of the beef cattle production system In Central America and southern tropical Mexico, cattle production systems on moderately acid soils commonly use living fences of leguminous multipurpose nitrogen-fixing trees such as Gliricidia sepium and Frythrina spp In this way, fence maintenance cost is reduced, some shade for animals is provided, and a source of feed is available for use during the dry season

These are a few examples of naturally occurring silvopastoral systems in the humid tropics As can be realized, totally integrated systems occur mostly in Southeast Asia, where cattle and small ruminants are a byproduct of plantations By contrast, in Latin America, trees are used mostly in support of the predominant cattle industry (fence, forage, shade, nitrogen fixation) or as a byproduct of the predominantly cattle-producing systems

RESEARCH RESULTS

The behavior of silvopastoral systems in a given ecological environment is mainly affected by interactions among their three components trees, pastures, and animals The great majority of information available deals with relationships between two of the three components Let us then analyze interactions between trees and pastures first, followed by those between trees and grazing management, as well as the shading effect on pasture species

1 Interaction of trees and forage plants

Peck (1988) suggested *Gliricidia sepium*, *Erythrina* spp , *Jathopa carcas*, and *Euphorbia cotinifolia* as potential living fence-post species, based on their capacity to root from stakes As shown in Table 1, some of these species, such as *Erythrina poeppigiana*, could also improve the crude protein content of grasses underneath, without reducing their dry matter yields (Daccarett and Blydenstein, 1968) On the other hand, grasses and legumes as cover crops in plantations contribute to the recycling of nutrients in the system Chee Yan Kuan (1981) reported about 300 kg of N, 20 kg of P, 100 kg of K, and 20 kg of Mg being recycled by a legume mix over five years in a young rubber plantation This was by far greater than the recycling capacity of the native grassland made up of *Axonopus compressus*, *Paspalum conjugatum*, or the indigenous weed bushes (Table 2) Table 3 presents the effect of three different covers on the growth of rubber trees after five years *Imperata cylindrica* does not contribute to recycling of nutrients and probably competes with the trees, resulting in smaller trees than those that have the cover of *Axonopus compressus* and *Paspalum conjugatum*, or the legume mix, regardless of soil type

In Sri Lanka, Ferdinandez (1972) reported the effect of three improved grasses on coconut yield, compared with the weeds that naturally grow under the trees (Figure 2) *Brachiaria milliformis* and *Brachiaria brizantha* pastures favor productivity over time of the coconut plantation, while *Panicum maximum*, with higher soil nutrient demands, competes with the trees, thus reducing coconut yields

Figure 3 shows the dynamics of dry matter on offer in different sown and native species grazed with two beasts/ha, under a five-year- old oil palm plantation The rapid decline of the sown species, *Stylosanthes guianensis* and common Guinea grass (*P maximum*), contrasts with the increase and recovery of the native shade-tolerant grass *Axonopus compressus* Peng and Ibrahim (Table 4) study the dry matter yield of separate grasses under a closed canopy of oil palm plantation As can be seen, yields are low compared with the potential yield of these grasses in open environments, however, some of the species, such as *Axonopus compressus*, *Brachiaria decumbens*, *Panicum maximum*, and Figure 2 *Paspalum conjugatum*, are able to produce more than *Cynodon plectostachyus* and *Setaria sphacelata*, which are strongly affected by shading

Interaction of trees and grazing management

The relationship between tree growth/yield and grazing management tends to indicate that the higher the stocking rate the lower the effect of grazing on adjacent trees

The level of stocking rate is known to be inversely related to animal performance However, Chen et al (1978) reported that high stocking rates tend to favor tree productivity This can be explained by the effect of grazing on reducing root systems as well as water and nutrient competition of grasses in the sward (Table 5)

Reynolds (1981) conducted a grazing trial under coconuts in Western Samoa, including different improved grasses and the local grassland, grazed with a stocking rate of 2 5 steers/ha His results showed that animal production from improved pastures more than doubled the productivity of the local grassland, without a major change in coconut yields However, some grasses reduced coconut yields slightly more than others (Table 6)

Rika et al (1981) reported results from a grazing trial comparing different stocking rates on sown <u>Brachiaria decumbens</u> associated with <u>Centrosema pubescens</u> pastures, along with native grasses, in terms of animal production in relation to the local feeding system which utilized cut-and-carry native grassland materials supplemented with banana stems and coconut leaves This experiment also compared the effect of the improved pasture with that of the ungrazed plantation native grassland in terms of coconut yields The results of this trial are presented in Table 7, where liveweight gains on the improved grass-legume pasture are higher than the ones obtained with the local feeding system Coconut yields were also higher than those obtained with the ungrazed native grassland Higher liveweight gains were obtained with lower stocking rates, and higher coconut yields with higher stocking rates

In the Solomon Islands, Watson and Whiteman (1981) evaluated different stocking rates on an improved pasture made up of a mixture of three *Brachiaria* spp , together with the legume cocktail of *Centrosema pubescens*, Kudzu, and *Stylosanthes guianensis* This pasture was compared with the naturalized grassland made up of *Axonopus compressus*, *Paspalum conjugatum*, *Centrosema pubescens*, *Mimosa pudica*, and *Calopogonium mucunoides* A three-year average of liveweight gains and coconut yields for the different stocking rates in the two contrasting pastures is presented in Table 8 It should be noted that, during the experimental period, the sown pasture degraded to a dominance of the native species The naturalized sward gave significantly higher liveweight gains and better coconut yields

The scant data available would suggest that improved pastures could in general benefit tree growth, but that will depend on the type of pasture species used and grazing management applied The presence of trees could improve the quality of the adjacent pasture But shade will probably be one of the most important factors in the interaction Different canopy structures and spatial arrangements of trees will affect the amount of light interference, while pasture plants show different degrees of tolerance to levels of sunlight interception

Shading effect on pasture grasses and legumes

The effect of shading on pasture grasses and legumes was reported by Eriksen and Whitney (1982) Figure 4 shows the effect of increasing shade on dry matter yield of several pasture legumes While *Stylosanthes guianensis* linearly reduced productivity under increasing levels of shade, *Desmodium intortum* and *Centrosema pubescens* showed better tolerance to the reduction of full sunlight Figure 5 shows the effect of shading on dry matter yield of *Panicum maximum*, *Brachiaria decumbens*, and *Brachiaria milliformis* Some degree of tolerance to shading was shown (0%-30% shade) by these grasses This information is confirmed by Wilson and Wong (1982), who reported a positive response of *Panicum maximum* cultivar Green Panic to shade of up to 40% light interception Figure 6 presents the results of Toledo and Fisher (1988) on the response of *Andropogon gayanus* to increasing levels of shading in total dry matter yield and in terms of root, stem, and leaf partitioning This data confirms the capability of some C_4 grasses to respond to low levels of shading But, this positive shade response of C_4 grasses is not yet well understood In fact, Burton et al (1959) and Ludlow (1978) postulated that both growth and rate of photosynthesis of C_4 grasses are linearly reduced by shade A possible explanation of these latter findings could be that the effect of interception of solar radiation on photosynthesis and transpiration rates were confounded, suggesting that higher photosynthetic efficiencies were obtained at slightly lower transpiration levels Another possible explanation is that nitrogen levels in the tissues are increased with shade, implying that nitrogen content in leaves has an important effect on the efficiency of the plant photosynthetic system In fact, Fleischer et al (1984) reported an increase in nitrogen content of *Panicum maximum* with increasing levels of shade (Figure 7), corroborating the findings of Daccarett and Blydenstein (1968) reported earlier

It is clear that variability exists among grasses and legumes in their capacity to tolerate shade It must be recognized, though, that most improved grasses in the tropics have been collected originally in open grassland environments (tropical savannas) This is the case with *Hyparrhenia* spp , *Andropogon* spp , *Brachiaria* spp , and *Panicum* spp However, some grasses, such as *Axonopus compressus*, *Paspalum conjugatum*, and *Stenotaphrum secundatum*, do grow in the wild in shaded environments

Figure 8 shows data from Wong et al (1985) on the effect of shade on the cumulative dry matter yield of several grasses It is clear that *Panicum maximum* (common), *Brachiaria decumbens*, and *Setaria sphacelata* drastically reduced their productivity below 60% full sunlight In contrast, other grasses, such as *Panicum maximum* (Green Panic), tolerate higher levels of shading *Axonopus compressus* slightly increases productivity under shade, while *Paspalum conjugatum* is essentially insensitive to shading Similar work by Smith and Whiteman (1983) reported drastic reductions in yield of *Brachiaria decumbens* and some moderate decline in yield of *Brachiaria milliformis* and *Paspalum conjugatum*, contrasting with the more uniform performance of *Axonopus compressus* and *Stenotaphrum secundatum* grasses under shade The level of productivity potential of these grasses is lower than that of those which prefer full sunlight However, their competitiveness increases under shade (Figure 9) Winstead and Ward (1974) reported that *Stenotaphrum secundatum* does not change its rate of net photosynthesis and dark respiration under shade In contrast with *Cynodon dactylon* (Table 9), this finding suggests that *S secundatum* might be a C_3 tropical grass CIAT collected about 40 accessions of *Axonopus* spp , *Paspalum* spp , and *Stenotaphrum secundatum* under shaded environments in Southeast Asia, Africa, and Latin America These collections were evaluated in Quilichao by Toledo et al (1989) under open and shaded environments Some of the materials were not able to survive during the dry season under full sunlight, others reduced yields under open environments, and some were essentially insensitive to shade Variability exists within species and among them The most promising species from which to select shade-tolerant material were *Axonopus compressus*, *Paspalum conjugatum*, and *Stenotaphrum secundatum* It was found that their dry season performance depend on the depth of their rooting systems

Axonopus compressus was found to be the grass with the shallowest root system which enable them to utilize superficial water under shade without competing with trees for deep water and, consequently, it is drastically affected during the dry period in open environments Other shade tolerant grasses such as *Paspalum conjugatum* and *Stenotaphrum secundatum* have somewhat deeper root systems, which allow them to also perform well in the open Table 10 shows the positive effect of shading on root length at different depths of the soil profile in *Axonopus compressus* and the nonsignificant effect of shading in root development of *Paspalum conjugatum* and *Stenotaphrum secundatum* This work of Toledo et al (1989) concluded with the selection of a few accessions from these three species that have potential for association on tree plantations

RESEARCH NEEDS

The previously selected results summarize studies made on the integration of trees and pastures in the humid tropics It should be recognized that, so far, this integration is limited to occur only in specific environmental and farming conditions It should also be recognized that the integration of silvopastoral systems has an important potential role for the development of semi-intensive production systems of higher yield and sustainability for already deforested areas of the rain forests However, for the expansion of silvopastoral systems, several constraints of a biological and socioeconomic nature must be overcome

Biological constraints

This subject is more easily presented in components Let us first look at biological constraints for pasture species Given the promising results of research activities of the RIEPT (International Tropical Pastures Evaluation Network) and CIAT's Tropical Pastures Program for the development of acid-tolerant pasture legumes and grasses, the adaptation of pasture species to shade and compatibility with trees appear to be the most important biological constraints Even though the principles of grazing in open areas apply directly to shaded environments, the levels of intensity of grazing and days of utilization and rest will certainly require adjustments for the efficient utilization of the swards under tree canopies

The main biological constraint for tree species is adaptation to poor, acid soils At present grasses and legumes are becoming available for poor, acid soils, however, there are no commercial trees available for the typical Oxisols and Ultisols that predominate in rain forest environments Pictures 5 and 6, taken the same day, show *Gliricidia sepium* planted on the same date in two contrasting soils, a fertile Vertisol on the left and an Ultisol on the right Promising shrub species, such as *Cratylia floribunda* and *Flemingia macrophila*, shows better adaptation to acid poor soils Other important constraints for the integration of tree species are the slowness of establishment from seed and the difficulties of rooting from stakes for the easy establishment of trees and early grazing of pastures Finally, a technical constraint that is also important is the lack of knowledge about optimum densities and grazing management of plantations when used with pasture covers for animal production

Socioeconomic constraints

Technologies are not adopted if the socioeconomic environment is not appropriate and their use is not attractive to farmers In Latin America, pasture and cattle production have essentially no major socioeconomic constraints for development, in contrast with major limitations in relation to tree planting The constraints which arise are mainly occasioned by marketing Valuable fruit/timber species, such as Pupunha (piguayo) or Guaraná, have extremelly restricted market The long-term nature of timber tree investment and the risk related to future revenues are also constraints investments are made today and harvesting is several years ahead in an extremely dynamic economic world

Research priorities

On the basis of these constraints and in light of existing knowledge, the following research needs and priorities can be suggested

a) For the pasture component

- Including shade tolerance as a criterion in the collection and screening of forage grasses and legumes

- Studies on compatibility of pasture species with trees in terms of competition for water, soil nutrients, and allelopathic factors

- Adjustment of grazing management in terms of grazing intensity and days of occupation and rest These studies should be conducted with different animal species (cattle, sheep, goats)

b) For the tree component

- Collection and screening of multipurpose trees for adaptation to poor, acid soils

- Studies to characterize the ability of different species to root from stakes, for the purpose of providing living fence posts

- Regrowth capacity and palatability of different tree species after defoliation, for selection of plants to be used as forage trees

- Agroindustry and marketing of tree products for the expansion of their utilization in the humid tropics

c) Finally, the following research needs are suggested for tree/ pasture interaction

- Development of establishment methods, including timing, for the establishment of components and the use of inputs and financing of pioneer annual crops

- Studies on the biological and economic competition of trees and pastures in relation to tree densities, age of plantation, and carrying capacity of pastures under the tree canopy

- Studies and documentation of the N fixation capacity of tree and herbaceous legumes, and their effect on productivity and quality of the integrated silvopastoral system

- Studies to evaluate the effect of trees, pastures and grazing animals on soil physical and chemical conditions (compaction, OM%, pH) through time

- Studies to optimize the whole system in terms of integrated management for maximum productivity and conservation of natural resources

FINAL REMARKS

Silvopastoral systems offer great potential for the development of efficient, highly productive, and sustainable systems in the disturbed lands of the rain forests An intensive research effort towards study the integration of trees and pastures is required, in order to technically overcome the previously mentioned constraints by means of genetic development and improvement, systems management, and socioeconomic understanding

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Table 1 Dry matter yield and crude protein of grasses under different trees

Tree cover	Grasses*	
	DM yield (kg/ha)	Crude protein (%)
Leguminous		
Erythrina poeppigiana (Poró)	6390	8.4
Pithecolobium saman (Samán)	7200	6.7
Gliricidia sepium (Madero negro)	6390	6.5
Boraginaceae		
Cordia alliodora (Laurel)	7520	6.2
No trees	7500	6.0

* Mix of *Panicum maximum*, *Paspalum fasciculatum*, *Homolepis aturensis*, and *Digitaria decumbens*

SOURCE Daccarett and Blydenstein, 1968

Table 2 Total amount of nutrients returned to the soil by different cover plants over five years in a young rubber plantation

Cover plants	kg/ha			
	N	P	K	Mg
P phaseoloides + *C pubescens* + *Calopogonium mucunoides*	226-353	18-27	85-131	15-27
A compressus + *P conjugatum*	24-65	8-16	31-86	9-15
Indigenous bushes	13-117	3-10	46-140	3-18

SOURCE Chee Yan Kuan, 1981

Table 3 Effect of cover with *Imperata cylindrica*, naturalized grasses, and legumes on the growth of rubber trees over five years

Cover	Girth (cm)	
	Inland soil	Coastal soil
I cylindrica	16 3	23 9
A compressus + *P conjugatum*	36 3	40 1
P phaseoloides + *C pubescens* + *Calopogonium mucunoides*	39 6	41 4

SOURCE Chee Yan Kuan, 1981

Table 4 Dry matter yield of grasses under closed canopy of oil palm plantation

Species	DM yield (kg/ha/year)
A *compressus*	929 a
B *decumbens*	1728 a
C *plectostachyus*	63 c
P *maximum*	1029 a
P *conjugatum*	1146 a
S *sphacelata*	322 b

SOURCE Peng and Ibrahim, 1983

Table 5 Liveweight gains and oil palm yields resulting from grazing native sward under five-year-old plantation

Cover	Stocking rate (head/ha)	Liveweight gains (kg/head/day)	No of bunches/palm
Native pasture	1	0 304	6 7
	2	0 112	10 6
	0	--	5 2

SOURCE Chen et al , 1978

Table 6 Liveweight gains and coconut yield in coconut plantation combined with different grasses in Western Samoa, with a stocking rate of 2 5 steers/ha

Pasture	Liveweight gains (kg/head/year)	Coconut yield (nuts/ha)
Local	51 b	4407
I indicum	109 a	3812
B milliformis	155 a	4482
B brizantha	158 a	4053
B mutica	143 a	3065
P maximum	134 a	3497

SOURCE Reynolds, 1981

Table 7 Effect of sown improved grass-legume pasture and grazing on animal* liveweight gains and coconut yield in Indonesia

Treatment	Stocking rate (beasts/ha)	Liveweight gains (kg/head/day)	Nut yield (kg/ha/month)
Sown *B decumbens* + *C pubescens*	2 7	0 321	507
	3 6	0 313	516
	4 8	0 293	713
	6 3	0 249	779
Native grasses under coconut		--	483
Local feeding system**		0 235	--

* Bali cattle (*Bos banteng*) were used

** Animals fed on cut natural pasture + banana stem + coconut leaf

SOURCE Rika et al , 1981

Table 8 Effect of stocking rate and pasture type on liveweight gains and coconut yield over three years grazing under coconuts

Pasture	Stocking rate (head/ha)	Liveweight gains (kg/head/day)	Coconut yield (nuts/tree/year)
Sown*	1 5	0 398	87
	2 5	0 340	84
	3 5	0 273	96
Natural**	1 5	0 427	93
	2 5	0 368	90
	3 5	0 270	91
SE for comparisons within pastures		0 019	4

* *Brachiaria mutica* + *B decumbens* + *B humidicola* + *C pubescens* + *P phaseoloides* + *S guianensis*

** *Axonopus compressus* + *P conjugatum* + *C pubescens* + *Mimosa pudica* + *Calopogonium mucunoides*

SOURCE Watson and Whiteman, 1981

Table 9 Rate of net photosynthesis and dark respiration (mg CO_2/dm^2 land area/hr) of two grasses grown under two light environments

Grass	Light environment	Net photo-synthesis	Dark respiration
Cynodon dactylon	Sun	57 9 a	15 9 a
	Shade	29 4 b	5 6 b
Stenotaphrum secundatum	Sun	31 4 b	3 9 b
	Shade	34 1 b	5 4 b

SOURCE Winstead and Ward, 1974

Table 10 Root length (km/ha) in the soil profile of grasses under full light (-S) and shade (+S)

Soil depth (cm)	Shade level	*Axonopus compressus* (11 accessions)	*Paspalum conjugatum* (14 accessions)	*Stenotaphrum secundatum* (1 accession)
0-10	-S	7384	6327	9531
	+S	10816*	5741	8281
10-20	-S	1887	1967	3396
	+S	3199*	2132	2558
20-30	-S	1222	1304	1596
	+S	1643*	1243	1205
30-40	-S	732	1077	1363
	+S	1351*	1160	1305
40-50	-S	372	901	1187
	+S	875*	998	962

* Significant differences (P > 0 05) between shade levels

SOURCE Toledo et al , 1989

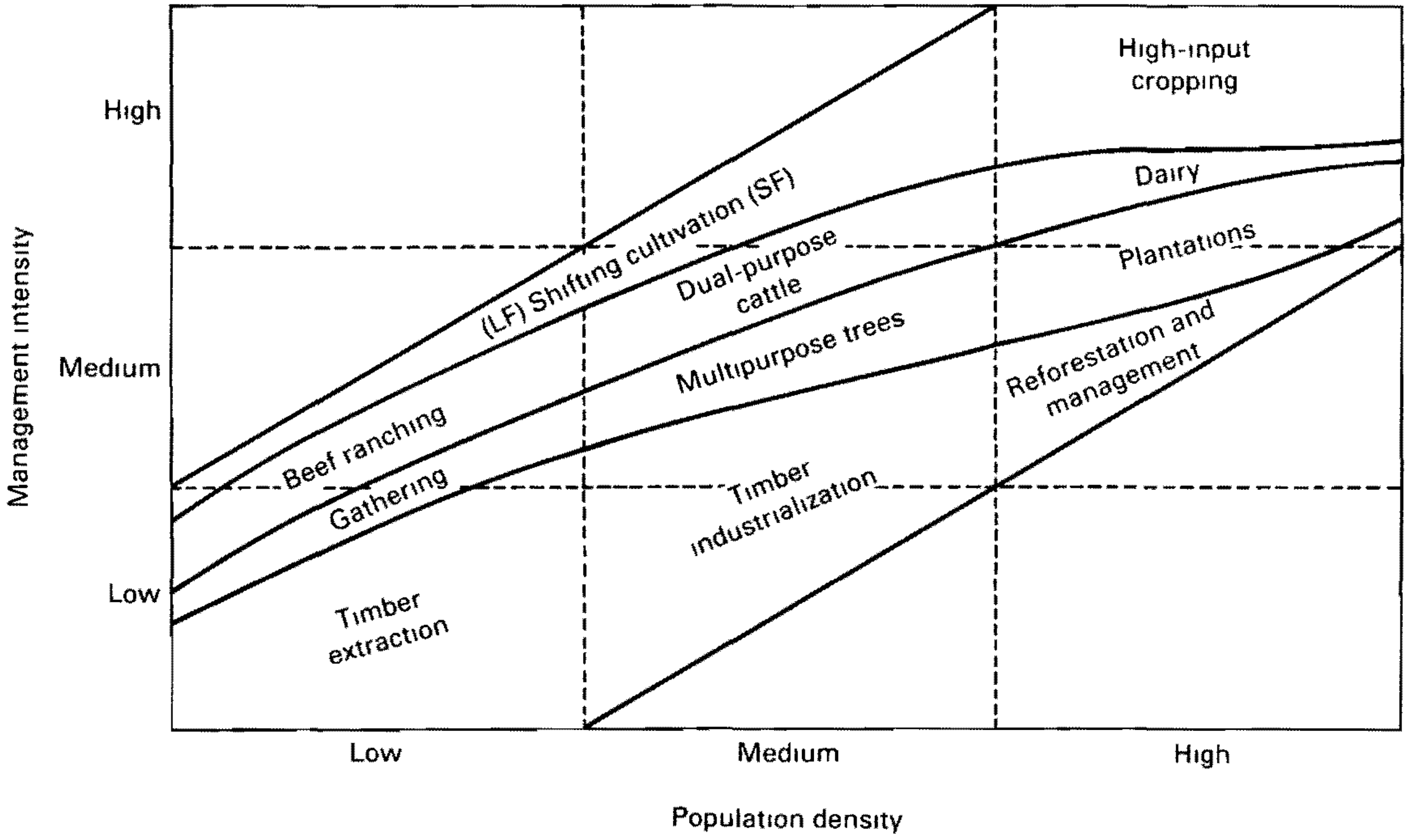


Figure 1 Land use and management intensity of different rural production systems in relation to population density LF = long fallow, SF = short fallow (Taken from Serrao and Toledo, 1988)

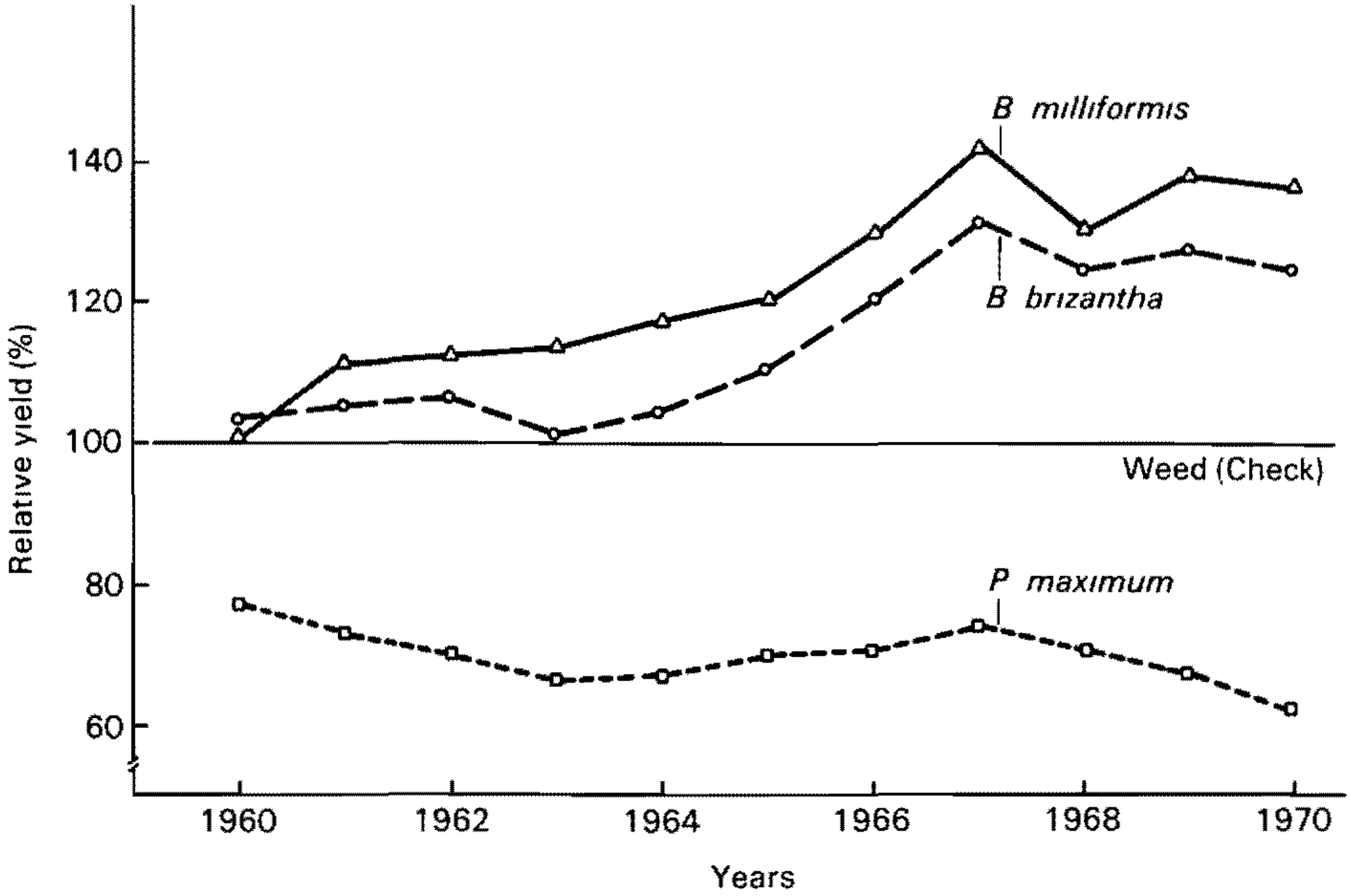


Figure 2 Relative yield of coconut under different grass and weed (control) covers (Adapted from Ferdinandez, 1972.)

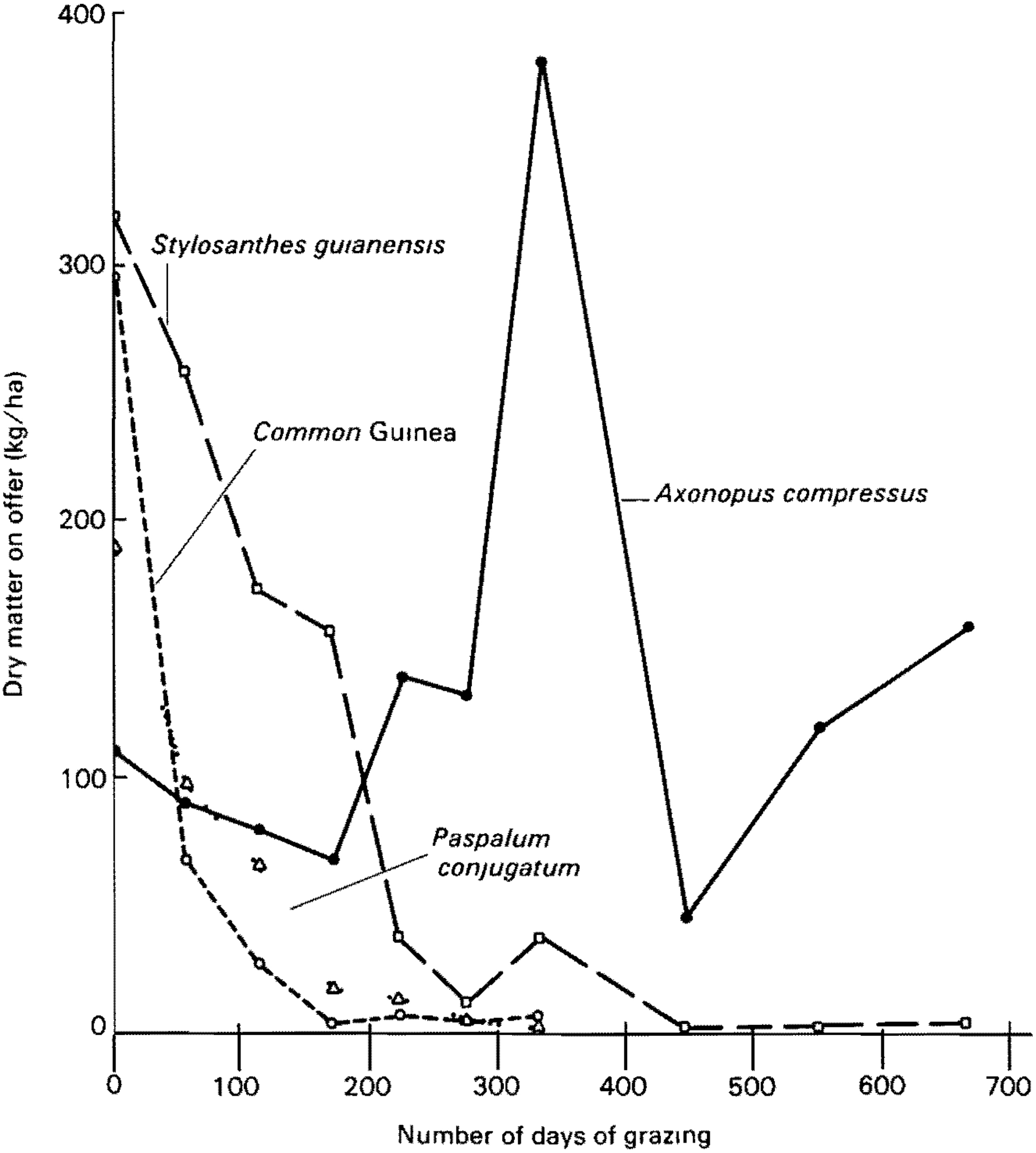


Figure 3 Dry matter on offer of sown and native species under grazing (2 beasts/ha) in a five-year-old oil palm plantation (Adapted from Chen et al., 1978.)

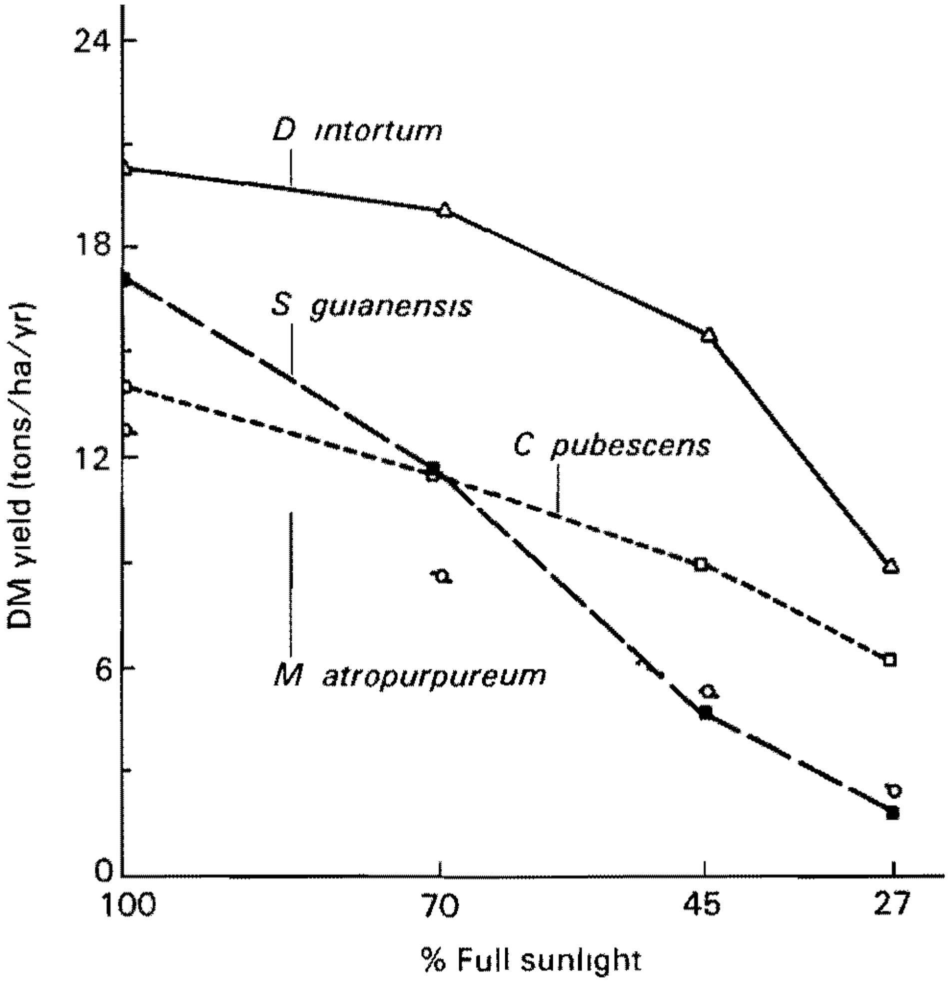


Figure 4 Shade effect on annual DM yield of legumes (Adapted from Eriksen and Whitney, 1982)

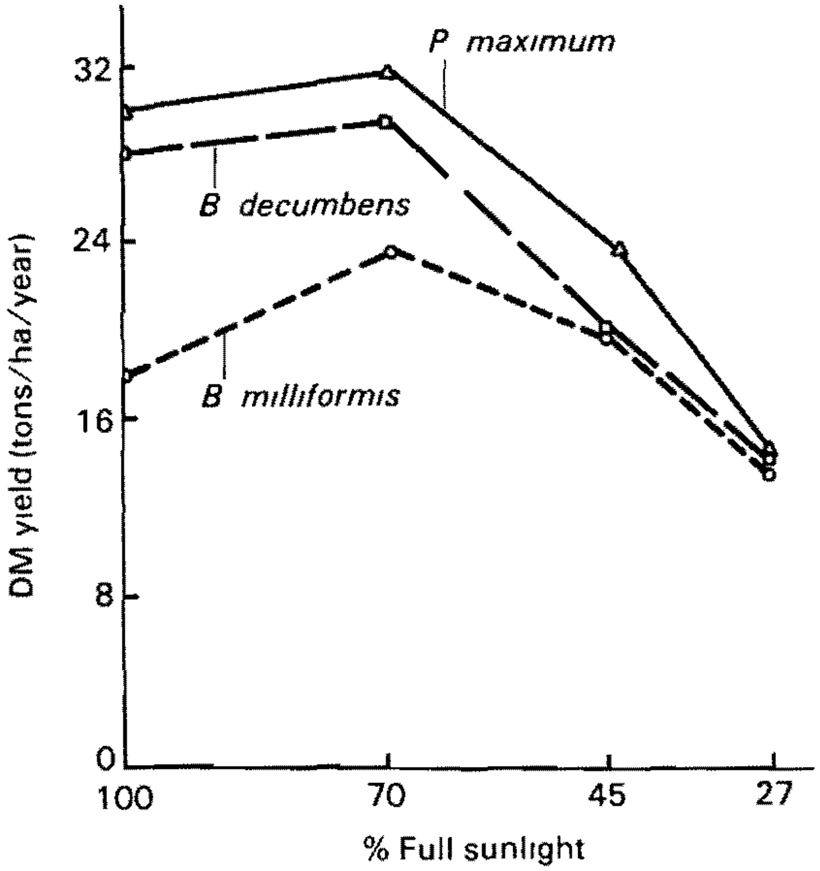


Figure 5 Shade effect on annual DM yield of grasses (Adapted from Eriksen and Whitney, 1981)

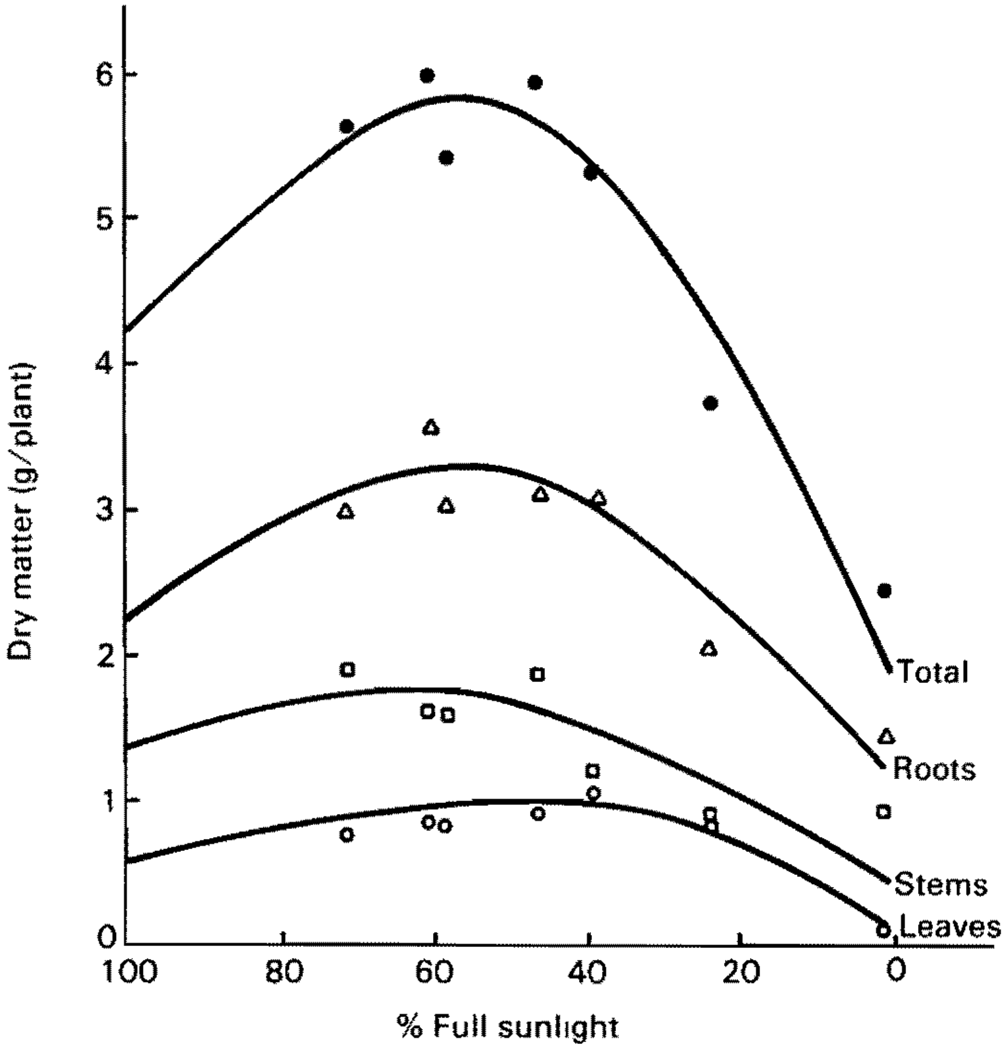


Figure 6 Yield of biomass of *A gayanus* after five weeks regrowth under different levels of shading (Adapted from Toledo and Fisher, 1988)

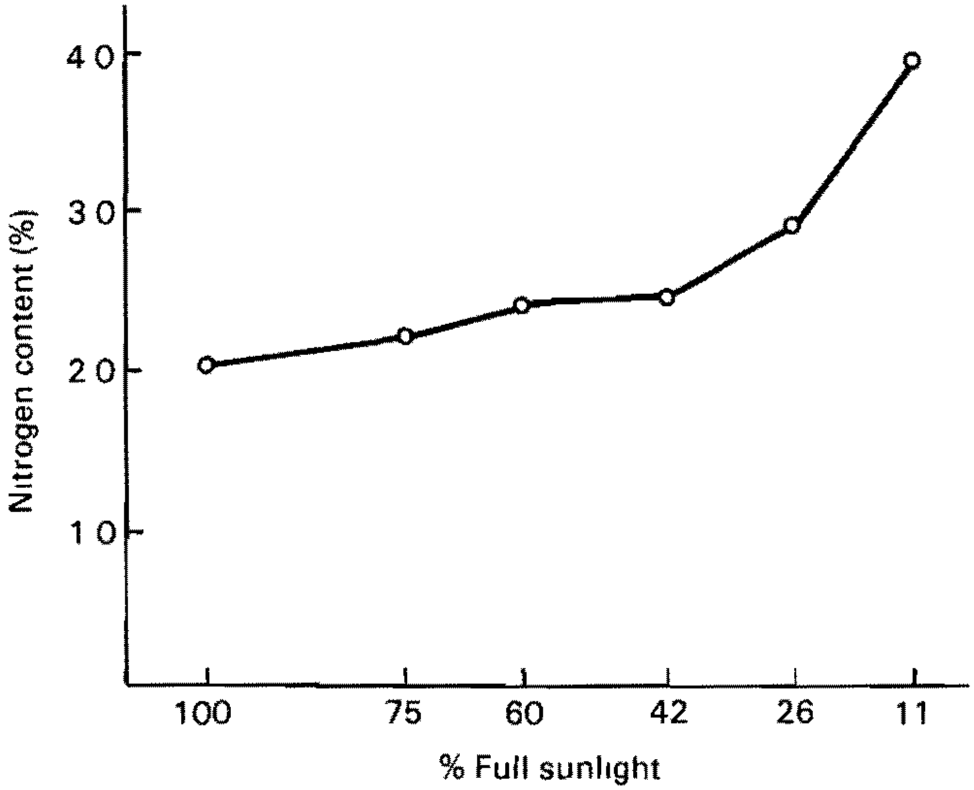


Figure 7 Effect of shading on N content in *P maximum* (Adapted from Fleischer et al , 1984)

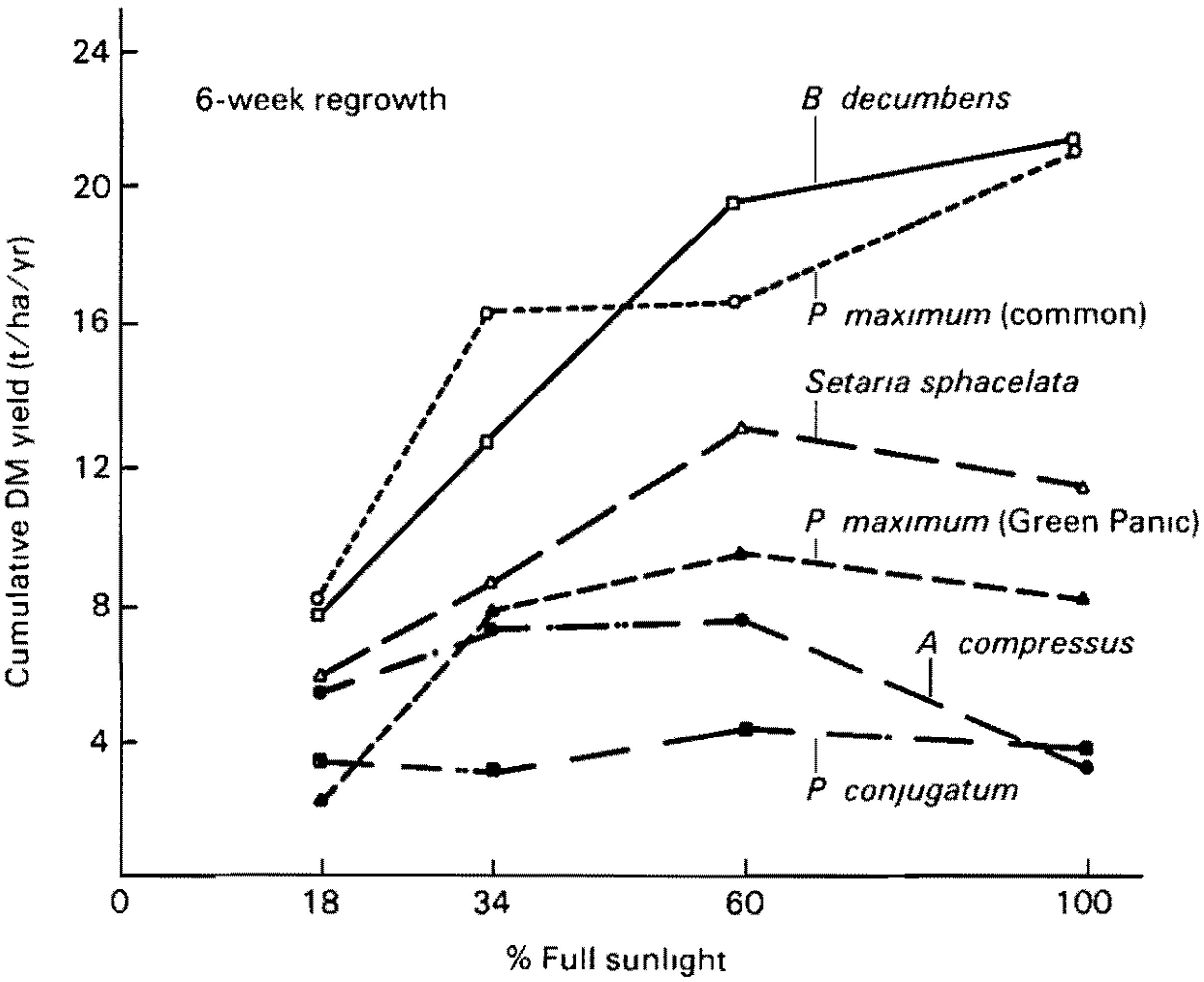


Figure 8 Mean annual dry matter production of six tropical grasses under four shade intensities and defoliated at six-week intervals (Taken from Wong et al, 1985)

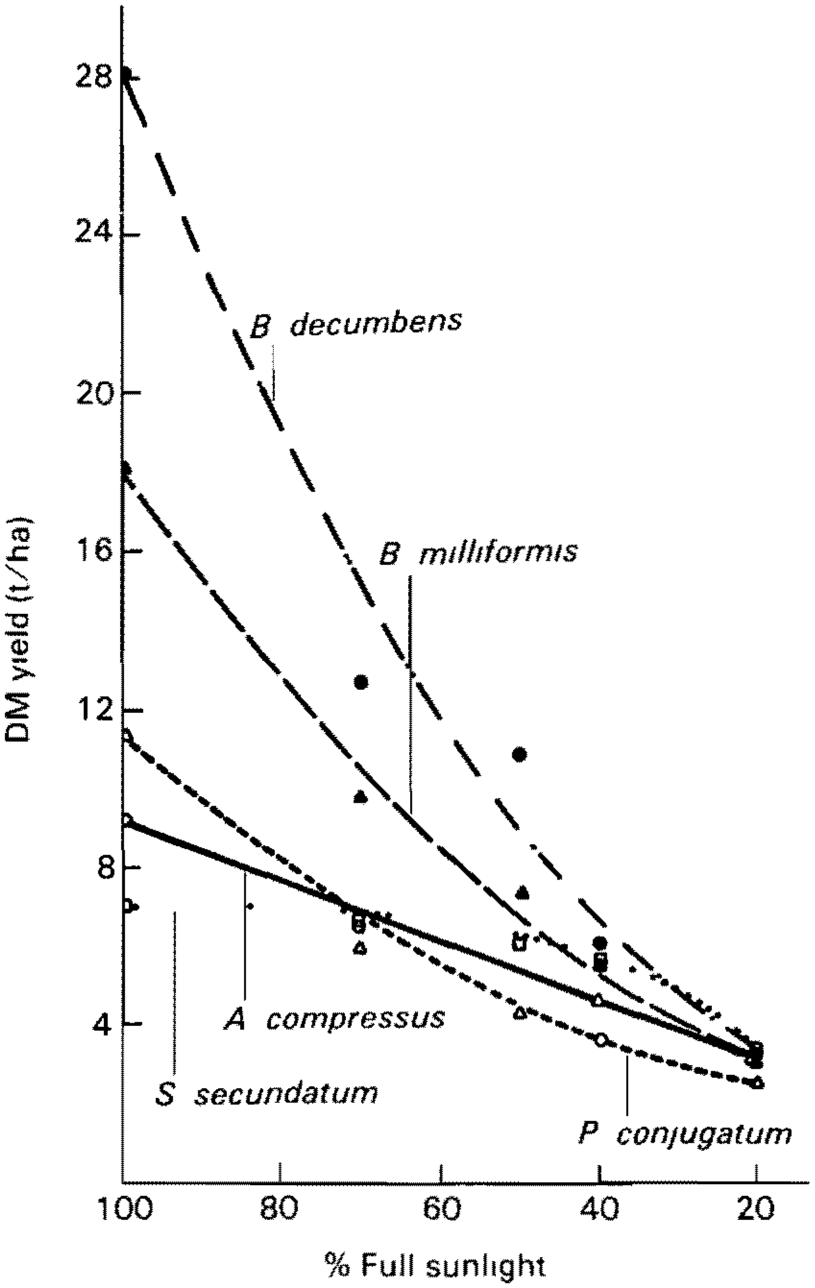
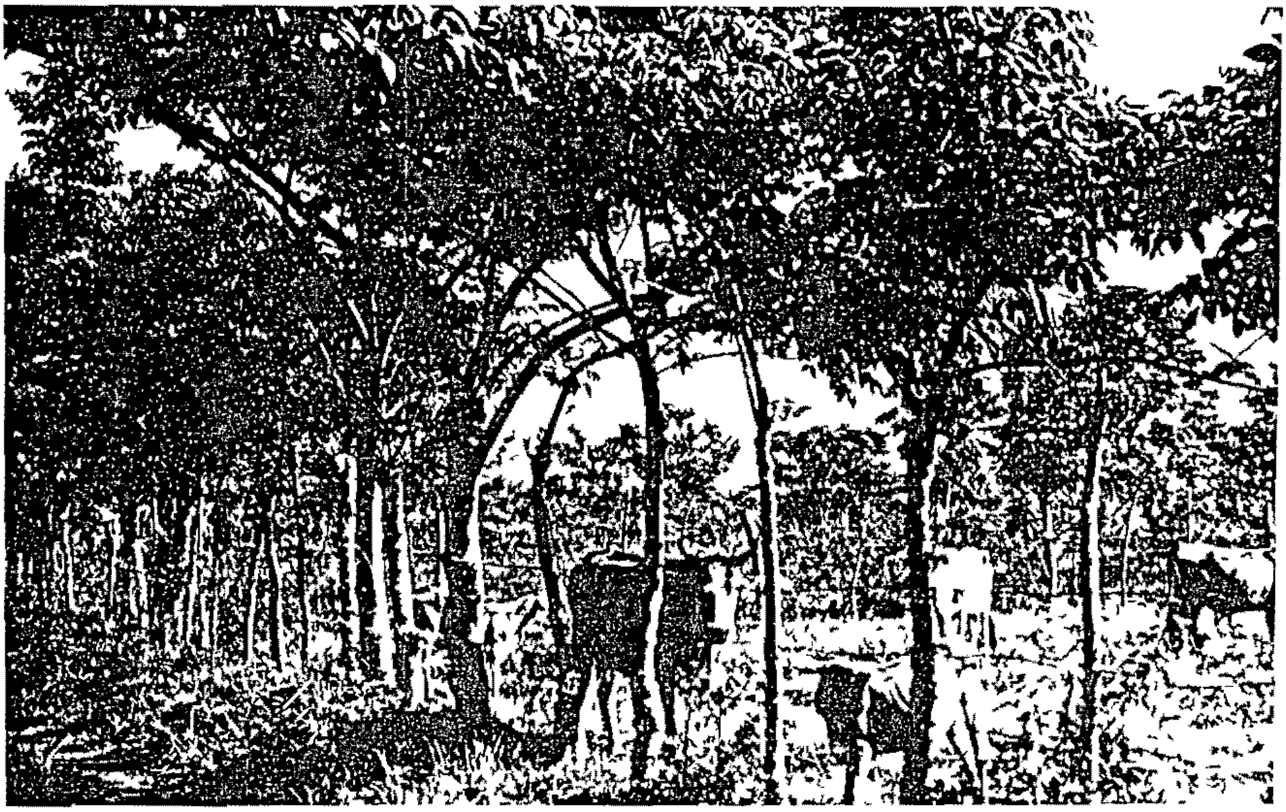


Figure 9 Total aboveground DM yield of grasses over six harvests at different light transmission sites under coconuts (Adapted from Smith and Whiteman, 1983)

Picture 1 Cattle grazing under a rubber plantation in Hainan island, China



Picture 2 Trees as living fences in Bugaba, Panama

Picture 3 Shade loving *Axonopus compressus* grass, in Quilichao, Colombia

Picture 4 Superficial root development of *Leucaena leucocephala* cv Cunningham, in a limed oxisol in the Brazilian, Cerrados