

## A REVIEW OF THE POSSIBILITIES FOR INTEGRATING CATTLE AND TREE CROP PRODUCTION SYSTEMS IN THE TROPICS

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### ABSTRACT

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A growing realisation that integrated livestock/tree crop production systems could possess advantages over some existing agricultural practices in the tropics, has resulted in considerable interest in these systems. The advantages and disadvantages of cattle/tree crop systems in the wetter and drier regions of the tropics have therefore been considered in this review, as have their basic technical requirements.

Three major cattle/tree crop systems can be identified. These are:

- grazing and/or browsing in natural forest;
- grazing or harvesting forage grown under planted trees; including that grown for the production of timber, firewood, nuts, fruit and industrial crops; and
- browsing and/or harvesting of tree forage.

Available data on the structure, operation and potential of the systems listed above in both wetter and drier regions are reviewed, with some emphasis on details of the cattle/coconut system as this has been more completely developed than any other livestock/tree crop system in the tropics.

### INTRODUCTION

Integration of cattle and crop production is not a new system of husbandry. It is probable that as soon as cattle were domesticated there was some integration. Cattle scavenged in the open fields after the crops were harvested, as they still do in many countries, and at other times they were probably driven into the forest to forage, as still occurs in the rain forest regions of Southeast Asia. Furthermore, in the pastoral areas there was always some integration in the sense that cattle were grazed in dry forest and savanna areas and that during the long dry season fodder trees were lopped so that cattle could feed on browse.

What is perhaps new is the realisation that cattle/crop integration can improve productivity per unit area of land. In a world in which the total population is increasing rapidly whilst the area of land available for agri-

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culture is finite, increasing productivity per unit area of land becomes vitally important. As a consequence there is now a search for viable systems that can properly exploit the possibilities that integration may offer.

Three major integrated livestock/crop production systems can be distinguished (Fig. 1) and it should be emphasized that other livestock, apart from cattle, can be integrated with tree crop production systems. However, in this paper only sylvo—pastoral systems will be reviewed in detail.

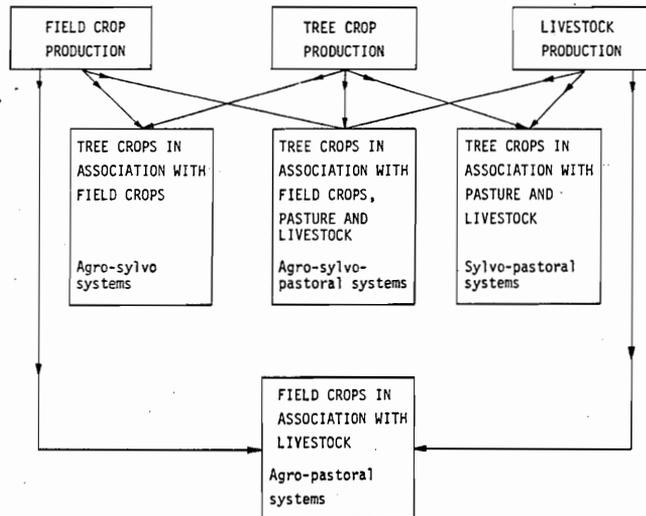


Fig. 1. Diagrammatic representation of the possible associations of field and tree crop production with livestock production.

Three major cattle/tree crop (sylvo—pastoral) systems can be identified in the tropics. These are:

- grazing and/or browsing in natural forest;
- grazing or harvesting forage grown under planted trees; including (a) trees grown for timber and/or firewood, and (b) trees grown for nut, fruit and industrial crop production as well as for timber and/or firewood; and
- browsing or harvesting of tree forage.

In addition, tree crops may be used in cattle production systems in order to provide live fences, wind breaks, shade trees and for soil and water conservation purposes. These uses will not be discussed in this review.

According to King (1979), only 24% of the world's total land surface is suitable for field crop production and less than half of this area (10.6% of the total land area) is at present cropped. Bene et al. (1977) state that half of all land in the tropics is suitable for agro-forestry operations. It would appear from this data that the possibilities for increasing the number and scope of integrated cattle/tree crop production systems are considerable.

## THE ADVANTAGES AND DISADVANTAGES OF CATTLE/TREE CROP SYSTEMS

The situation in the wetter and drier regions of the tropics will be considered separately as cattle/tree crop systems have distinct and different characteristics in these different climatic environments.

### *The wetter regions of the tropics*

A major advantage of cattle/tree crop systems in the wetter tropics is that to a limited extent they simulate the rainforest ecosystem that they replace. This has the following biological advantages:

— Available solar energy is used rather efficiently by the plant biomass due to the vertical stratification of vegetative components of the system (Fig. 2) and the soil is protected from severe erosion by two or more plant storeys.

— There is usually some vertical stratification of the root systems of the different plant species, their roots occupying different soil horizons, thus ensuring that as wide a range as possible of essential nutrients are removed from the soil. At the same time, the presence of trees in the system means that there is always a large amount of plant debris falling to the ground. These two factors facilitate the recycling of nutrients removed from the soil, whilst at the same time the plant debris provides some additional protection for the soil against erosion (Fig. 2).

— If the trees used in the system are legume species or other species that can fix nitrogen, such as the alder (*Alnus acuminata*) that is planted in the Costa Rican highlands and fixes nitrogen through the agency of a fungus *Actinomyces alni*, these assist in improving soil fertility, as does the use of forage legumes in the pasture mixture grown under the trees. Indeed, there is the possibility of a long-term improvement in soil fertility due to the effect of cattle continuously grazing grass legume pastures. Where cattle are grazed under fruit or nut trees, soil fertility may be further enhanced if tree crop by-product feeds, such as coconut meal, are returned to the tree crop area and fed to cattle.

Apart from the biological advantages cited above, there may also be the following economic advantages.

— A reduction in the annual cost of weeding under the trees, as grazing reduces weed competition. The first use of cattle in many coconut plantations was as 'weeders' or 'brushers' and foresters are now appreciating that the use of cattle in forest plantations may appreciably decrease annual weeding costs.

— A diversification of product output and labour input, with possibly a more effective utilisation of labour on an annual basis.

— A possible increase in total product output per unit area of land, and where cattle/tree crop systems replace monocultural tree crop systems, an increase in the total value of output per unit area, as animal products normally possess a higher unit value than plant products.

— The possibility of managing higher grade and therefore more productive cattle under tree crops, than on open grazing land in the same climatic environment. This possibility exists because ambient temperatures and therefore heat stress on the cattle is generally lower on grazings under tree shade than on open pasture. In addition, there may be other factors in a tree crop micro-environment that help to ameliorate heat stress, such as the local air currents caused by the constant up and down movement of the fronds of coconuts.

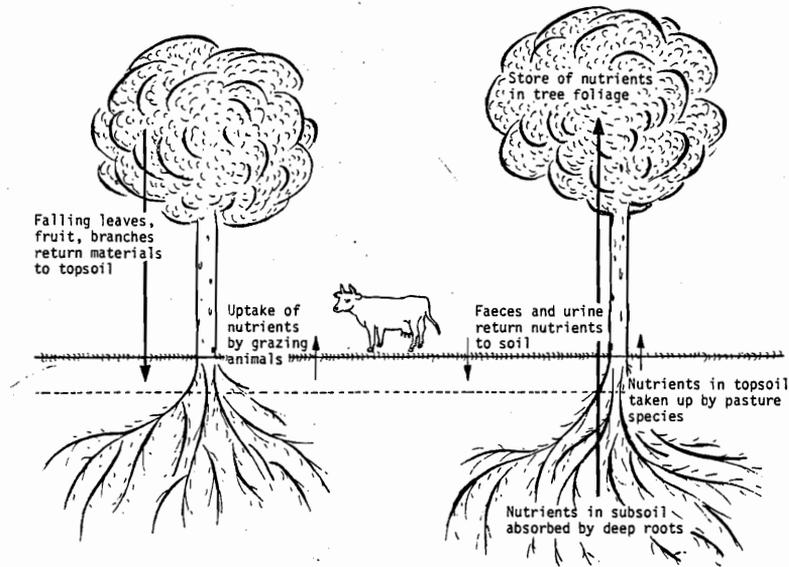


Fig. 2. Diagrammatic representation of components of a livestock/pasture/tree crop system.

If, in the wetter tropics, there are such obvious advantages in integrating cattle with tree crop production, the question may be asked as to why this is not the most common system employed? Particularly as vast areas of rain forest are being felled in order to establish extensive cattle ranches.

The main reason appears to be that these systems are managerially more complex than monocultural systems. They therefore require a higher standard of management on the part of the estate manager or small farmer, together with additional infrastructure and capital. In addition, they also pose some difficult technical and techno-administrative problems, and, with the exception of the cattle/coconut system, the overall effects of species competition and the interactions between tree crop, forage crop(s) and cattle, have not generally been investigated. There is also a general lack of practical experience in the management of these systems, as apart from the areas where there are cattle/coconut farms, there are few regions in the tropical world where there has been any major attempt to integrate cattle with other fruit or nut tree crops or with planted forest trees. As

a consequence the practical and experimental evidence for the probable superiority of cattle/tree crop systems in wetter tropical environments is very limited, the literature on the subject being mainly concerned with future plans.

### *The drier regions of the tropics*

The situation is somewhat different in the drier regions of the tropics. Dry forest, such as the *miombo* of Africa and similar ecosystems in the Americas, Asia and Oceania usually possess very open canopies so that forage plants thrive beneath them. Dry forests and savanna (open grassland with scattered trees), characteristic plant associations in the drier regions of the tropics, are usually rich in legume tree and pasture grass species but poor in pasture legume species. They have been traditional grazing areas since man first introduced domestic livestock to the regions, so that they could be designated as traditional livestock/tree crop system areas. These traditional livestock/tree crop systems possess the biological advantages discussed in the previous section, but they are rather fragile ecosystems, easily destroyed by a combination of fire and continuous overgrazing.

In drier regions the trees are not only valuable as a source of nutrients to enhance soil fertility and shade for livestock but they also protect the soil from excessive erosion and are a major source of nutritious forage during the long dry season. Continuous overstocking depletes the ground vegetation, induces erosion and, combined with continuous firing undertaken to induce new grass growth, reduces the number of tree species to those that are fire resistant. If fire resistant trees are then continually lopped to obtain forage in the dry season these dry land ecosystems rapidly degrade, a process only too prevalent throughout the drier regions of the tropics.

The major problem, therefore, in the drier regions of the tropics is not to learn how to introduce new cattle/tree crop systems, but to stop and if possible reverse the degradation of traditional cattle/tree crop systems.

### BASIC TECHNICAL CONSIDERATIONS FOR THE INTEGRATION OF CATTLE WITH TREE CROPS

In any cattle/tree crop system maximum productivity will be obtained when the maximum quantity of animal products are produced without any decrease in the production of the tree crop and vice-versa. If the genetic quality of the cattle and their health and management are optimal for the environment then the productivity of the cattle depends upon the growth and efficient utilisation of the maximum quantity of highly nutritious forage. Forage production, in turn, depends upon the amount of light (radiation) available, the availability of water and plant nutrients, the type of forage species utilised, their management and the management of the cattle.

The interactions of all these various factors will be considered separately for cattle/tree crop systems in the wetter and the drier regions of the tropics.

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*The wetter regions of the tropics*

*Light.* The amount of light available at ground level for forage growth depends upon the species, the spacing and the age of the tree crop. As trees mature in plantations and a canopy forms, the intensity of light at ground level decreases. In old, mature stands it may increase again as the canopy often decreases in density with age and gaps are formed by the death of individual trees. In natural rain forest, light intensity at ground level may be very limited but varies from area to area and may be high where trees have recently died. This situation creates a managerial problem for integrated systems as the amount of forage available per unit area in plantations fluctuates according to the age of the tree crop and in natural forest according to a variety of circumstances. This fluctuation may be limited, as in the case of forage growth under tall mature coconuts or widely spaced forest trees. Light intensity at ground level in a stand of mature coconuts is generally considered to be of the order of 50–60% of the total (Watson, 1977), but may be higher as Steel and Humphreys (1974) stated that in tall coconuts spaced 12 m apart in Bali, Indonesia, noon light at ground level was 77–80% of the total available. On the other hand the fluctuation in forage availability may be extreme, as is the case in rubber plantations or closely spaced forest trees, as little light filters to the ground through the canopies of mature trees.

Although some forage plants are more shade tolerant than others, the general effect of decreased light intensity is to reduce productivity. Eriksen and Whitney (1977), working in Hawaii, subjected six grasses and six legumes to light intensities that varied from 100 to 27% of the total available. The dry matter yields of the fertilised grasses varied from 16–40 to 8–15 tonnes per ha per annum at 100 and 27% light intensity, respectively; whilst the yields of the legumes varied from 12–23 to 2–10 tonnes per ha per annum at 100 and 27% light intensity, respectively. At the same time the productive ranking of the grasses and legumes altered with decreasing light intensity; presumably a reflection of species differences in shade tolerance. At low light intensity *Panicum maximum*, *Brachiaria brizantha* and *Brachiaria miliiformis* were most productive. The ranking of the legumes for shade tolerance was first *Desmodium intortum*, then *Centrosema pubescens*, *Desmodium canum*, *Leucaena leucocephala*, *Macroptilium atropurpureum*, and *Stylosanthes guianensis* cv. Schofield. This ranking confirms a report of Whiteman, Bohoquez and Ranacou (1974) who stated that *D. intortum* is more shade tolerant than most other legumes. The investigations of Eriksen and Whitney (1977) also confirmed a report of Ludlow, Wilson and Heslehurst (1974) that shading increases the shoot/root ratio of forage plants and increases the nitrogen and mineral content of grasses.

These investigations suggest that the selection and use of suitable shade tolerant forage species is of paramount importance in the management of cattle/tree crop systems.

*Plant nutrients.* There is some evidence that the introduction of cattle and sown forage into tree crop areas may improve soil fertility. Grazing cattle, by cycling nutrients, may improve overall nutrient availability, as Fernandez (1970) showed that grazing versus no grazing on pastures under coconuts improved yield from 5780 to 10180 nuts per ha over a 4-year period. Also, sown forage may, after a number of years, so improve the soil structure that the water relations of the tree crop are improved (De Silva, 1961).

Unless a soil is extremely fertile and all nutrients are present in excess of the demands of the tree crop, the under-storey vegetation, whether it be weeds, naturalised forage, planted forage or crops, will compete with the tree crop for nutrients and water. Competition for nutrients could in theory be eliminated by the application of a sufficient quantity of fertiliser. Santhirasegarum (1966) has shown, for example, that when forage is grown under coconuts there is only a negligible reduction in the yield of nuts if there is a high availability of moisture and plant nutrients.

In practice there is obviously an economic limit to the quantity of fertiliser that can be used, but it is essential when planning a fertiliser programme to consider the different nutritional needs of the trees and the forage crops. The use of legumes in the forage mixture is essential, as there is not only some evidence that they may be somewhat more shade tolerant than most grasses (Watson, 1977; Whiteman, 1977), but they also contribute to the total quantity of nitrogen available to both crops.

The species of tree used may also affect the availability of plant nutrients and consequently the nutritional value of the forage grown beneath the trees. At Turrialba, Costa Rica, the effect of four tree species (three of

TABLE 1

The effect of trees on the nitrogen content of the soil in which they grow and on the crude protein and fibre contents of the forage growing beneath them

Tree	% Total N in soil		% Crude protein in forage	% Fibre in forage
	at 0-20 cm	at 21-40 cm		
<i>Erythrina poeppigiana</i> (poró; legume)	0.35	0.15	8.37 <sup>a</sup>	29.16
<i>Gliricidia sepium</i> (Madero negro; legume)	0.32	0.18	6.54	29.94
<i>Pithecolobium saman</i> (saman; legume)	0.38	0.18	6.75	28.98
<i>Cordia alliodora</i> (laurel)	0.25	0.15	6.17	29.04
Control (no trees)	0.28	0.16	6.00	31.86

<sup>a</sup>Significantly greater than the control.

Source: Deccarett and Blydenstein (1968).

them legumes) on the percentage of total nitrogen in the soil below them and on the nutritional value of the forage grown beneath them has been studied by Deccarett and Blydenstein (1968). Data from this investigation is provided in Table 1. The canopy was not very dense and the poró trees were large, whilst the other trees were smaller. The crude protein content of the forage under the trees was generally higher than that of the forage on open land; the forage under the poró trees possessing a significantly higher crude protein content. This data suggests that forage grown under legume trees may be more nutritious than the same forage grown in the open.

The special mineral nutritional needs of the cattle grazed under trees should be met by providing a suitable mineral mixture as a supplement.

*Water.* Unless irrigation water is available, plantation integrated cattle/tree crop systems are usually only viable in those regions where total annual rainfall is sufficiently high and seasonally well distributed to satisfy the demands of both crops. Santhirasegarum (1964) has stated that when total annual rainfall is more than 2000 mm and well distributed there is no problem in cattle/coconut systems but that when it is below 1300–1500 mm there can be direct and detrimental competition between the coconut and the forage crops for soil moisture. In areas where the total rainfall is marginal for cattle/coconut systems, young palms may be affected by the forage crop while mature palms remain unaffected (Ohler, 1969), whilst grazed forage has a less depressive effect on coconut yield than ungrazed forage (Ferdinandez, 1970). The relationship between the water demands of the forage crop and other tropical tree crops (including timber trees) has not been well established.

*Type of forage species utilised.* Reference has already been made to the value of legume trees and legumes in forage mixtures used in cattle/tree crop systems. Further details of suitable trees and forage plants will be provided in the sections concerned with specific cattle/tree crop systems.

*Management of forage and cattle.* Forage grown beneath trees can be cut and fed elsewhere or grazed 'in situ'. In the case of cattle/coconut systems there does not appear to be any particular advantage in growing forage grasses for 'cut and carry' operations. Indeed, if the forage is fed to cattle in yards located within coconut areas, the haphazard build-up of manure in the yards could provide an ideal habitat for breeding one of the worst pests of coconut, *Oryctes rhinoceros*, the rhinoceros beetle. On the other hand, forage for 'cut and carry' operations could be grown between rows of young rubber trees, oil palms or timber trees before the closing of the canopy.

A choice of grazing system exists. Cattle can be tethered to mature trees, grazed under the watchful eye of herders, or grazed unattended

m in fenced paddocks. Tethering under trees is practised by small farmers  
 n in many tropical countries. Salgado (1951) stated that in Sri Lanka 18 co-  
 n nut trees per head of cattle per annum were required for a rotational  
 as tethered grazing system. Herding is also practised where labour is cheap,  
 it but fenced paddocks are becoming more and more common as fences can  
 ge be relatively cheap to erect in a system where growing trees may be used  
 y as fence posts. The advent of the solar-powered electric fence has also  
 er made electric fences more economic.  
 e

es The species, spacing and age of the tree crop affects the microclimate  
 t. beneath the trees and hence the degree of heat stress on cattle. Sajise (1973)  
 e stated that on a sunny day ambient temperature within a coconut planta-  
 d tion can be 4°C below what it is on adjacent open land, though there is little  
 e difference under cloudy conditions. Relative humidity under the trees is  
 only higher in the afternoon. It is possible that ambient temperatures are  
 even lower under some forms of natural forest cover.

e Grazing cattle may affect the tree crop by eating and/or damaging the  
 1 leaves, stems and growing tips of young trees. Cattle should therefore be  
 s kept out of young coconut plantations until the growing tips of the young  
 ) trees are above their heads; alternatively individual trees can be fenced.  
 t The bark of some older trees may also be damaged by cattle and where  
 l trees are grown on heavy soils cattle may puddle the soils and adversely  
 7 affect free drainage. Plucknett (1972) stated that soil compaction could  
 ; be a problem on heavier soils during wet conditions, particularly if pastures  
 | beneath the trees are overgrazed. Thomas (1978) has shown that in Indo-  
 ; nesia, where heavy textured soils and a high water table are to some extent  
 characteristic of conditions in oil palm plantations, grazing cattle may  
 depress fruit yields by 1.0–1.5 tonnes per ha.

### *The drier regions of the tropics*

*Light.* Under dry forest conditions the trees are generally widely spaced  
 and the canopy is usually rather open whilst in savanna the trees are in-  
 variably rather widely spaced. The same conditions occur in dryland fruit  
 and nut plantations unless the trees receive irrigation water. Consequently  
 a higher percentage of available light is received at ground level than is  
 normal in cattle/tree crop systems in the wetter tropics and shade tolerance  
 is not such an important ground species characteristic.

*Plant nutrients and water.* In the drier tropics competition for plant nu-  
 trients and water — particularly for water — between trees and bushes and  
 the plants growing beneath them can be very severe. It is probable that a  
 dense stand of trees and shrubs will decrease the productivity of the ground  
 cover, but on the other hand elimination of the browse species will increase  
 the vulnerability of livestock to a lack of suitable feed in the dry season  
 and during droughts. With adequate tree and bush spacing, however, grass

production may be of higher quality and last longer under the shade of fodder trees. In the Sahel zone of West Africa the productivity of *Pennisetum pedicellatum* is about twice as high under shade trees as it is in the open and the grasses do not dry out so quickly (Le Houérou, 1978). The same effect has been noted in Botswana, where at the beginning of the dry season *Panicum maximum* growing under forage trees remains green for up to six weeks longer than it does in the open (Le Houérou, 1978). Despite the availability of data suggesting the tree cover may improve ground cover productivity, many pasture specialists advocate a reduction in the number of trees and bushes in savanna and semi-arid grazing lands in order to increase the production of ground forage. Beale (1973) investigated the relationship between the tree density and the production of tree and ground forage at two sites in an *Acacia aneura* dominated ecosystem in sub-tropical Queensland, Australia. Details of the tree density and the tree and ground forage yields are provided in Table 2. It will be noted that total yields of forage were lowest at the drier site and that they declined with decreasing tree density whilst at the wetter site total yields were of approximately the same order whatever the tree density, and tree forage and ground forage yields were inversely related. This data suggests that in drier areas, where competition for plant nutrients and water is severe, there is advantage in encouraging a dense tree cover in a tree crop/cattle system and depending more on tree forage than on ground forage as a cattle feed; assuming that the tree forage is readily available, palatable and not toxic for cattle.

The use of fertilisers in tree crop/forage systems is not likely to be economic unless the tree crop is of considerable value. Also, as in the wetter

TABLE 2

The relationship between tree density and the yield of tree and ground forage

Location		Yield of forage (kg/ha)			
		Density:	40	160	640
Boatman, Queensland	Tree		240	810	2330
	Ground		2030	1150	180
	Total		2270	1960	2510
Monamby, Queensland	Tree		180	680	2090
	Ground		460	540	230
	Total		640	1220	2320

The ecosystem was *Acacia aneura* shrubland in sub-tropical southwest Queensland, Australia. Major ground species were *Aristida* spp., *Neurachne mitchelliana*, *Danthonia bipartita*, *Sida* spp. and *Trachymene* spp.

Source: Beale (1973).

tropics, the tree species utilised may affect the availability of plant nutrients within the system, so that the use of legume trees should be encouraged.

*Type and forage species utilised.* On account of the necessary wider spacing of trees in the drier tropics a very large number of grass species can be grown beneath them and readers should consult standard text books with regard to the most suitable ground forage species for any particular region of the drier tropics. Major browse species are discussed and some species listed in Table 5.

*Management of forage and cattle.* Management of both the forage species and the cattle, is of major importance in the fragile ecosystems of the drier tropics. It is necessary to maintain an equilibrium between the forage trees, the ground cover and the number and type of livestock. In the West African savanna a density of 100–400 trees and/or shrubs per ha, according to rainfall, is considered to be desirable (Bille, 1977) as trees and shrubs at these densities should provide sufficient browse during the dry season to provide 20–30% of the nutritional requirements of the livestock. The use of fire as a managerial tool should only be used sparingly, as continuous firing will almost inevitably lead to reduction in the number of species and to some degradation of the system. Overstocking must inevitably degrade the system.

#### GRAZING AND/OR BROWZING IN NATURAL FOREST

##### *The wetter regions of the tropics*

Only limited light penetrates to the forest floor in virgin rainforest, consequently there is often little or no ground forage suitable for grazing and only very small quantities of browse available. This is one reason why there are so few ruminant game species in equatorial rainforests. The cutting of timber trees and shifting cultivation in areas adjacent to villages opens up the forest canopy, increasing light intensity at ground level and hence the growth of forage species. Under these circumstances, and at relatively low density, village livestock can be grazed in the forest, as often occurs in Africa and Southeast Asia.

In some districts of Sumatra, Indonesia, what is possibly the simplest cattle husbandry system in the world is practised, utilising natural forest as a source of forage. At night, the cattle together with water buffalo and a few sheep and goats sleep under their owner's house. At dawn, untended, the animals trek out of the village into the surrounding secondary rainforest, in which crop gardens are protected by fences. They spend the day in the forest, grazing and browsing, returning without supervision

to the village at dusk. Tigers kill the occasional animal, but the villagers appear to regard this minimal input/output system as perfectly satisfactory.

Some attempts are being made to investigate natural forest grazing systems. One project being in Western Samoa, where a major effort is being made to introduce cattle into village economies. There are obviously some possibilities for the development and extension of this system, but to date little factual data appears to be available.

### *The drier regions of the tropics*

As stated previously, dry forests and savanna are traditional grazing areas so that the livestock systems in these regions could be considered as traditional livestock/natural forest systems. The grazing problems of pastoralists in these regions have been described elsewhere in detail and will not be considered in this review. Some types of browse and the problems associated with its utilisation are discussed in the following sections.

#### GRAZING OR HARVESTING FORAGE GROWN UNDER PLANTED TREES

Cattle may be grazed under trees planted specifically for timber and/or firewood production or under perennial tree crops planted for nut, fruit or industrial crop production, and ultimately used for timber and/or firewood production.

#### CATTLE/TIMBER AND/OR FIREWOOD TREE CROP SYSTEMS

There is a great deal of discussion of these systems in technical journals but little investigational data is available. To date, what is available has been mainly derived from investigational work conducted in the wetter tropics, but there is now very considerable interest in the possibilities that these systems present in the drier tropics.

### *The wetter regions of the tropics*

Some details of systems in the wetter sub-tropics are included in this section as they may also provide some guide as to the most suitable management systems in the wetter tropics.

Donohoe (1980), discussing integrated production in sub-tropical Florida, stated that tree spacing is a most important factor. He recommended that where pine forests are used for grazing, trees should be spaced  $2 \times 5$  m apart or if they are planted in strips 9 m apart, spacing can be 2-3 m within the tree strip. Under Florida conditions the dry matter forage yield and approximate carrying capacities were as follows:

Stage of growth of pine	Dry matter forage yield (kg/ha)	Cattle carrying capacity (l.s.u./ha) <sup>a</sup>
Seedling/sapling	2900—3400	0.60—0.75
15 cm trees	1600—2900	0.40—0.60
Poles: sawn young timber	700—1600	0.20—0.40

<sup>a</sup>In Florida one l.s.u. is the quantity of forage required by one 500 kg liveweight cattle in one year.

The above data suggests that under southern Florida conditions, in young pine forests cattle productivity could be of the order of 100—200 kg live-weight per ha per annum.

According to Budowski (1980) integrated systems are common in the humid forest zones of Mexico, Central America and northern South America. This observation is supported by the results of a survey of 230 small farms in Costa Rica, conducted by Avila et al. (1979). They found cattle/perennial crop systems on 66% of the farms, the perennial crop being timber trees on 24%. Apolo (1979) has stated that systems that closely resemble the forest system are likely to be the most stable and productive and that some of the most suitable timber trees to use in these systems in the wetter tropics of the Americas are poró (*Erythina poeppigiana*), madero negro (*Gliricidia sepium*) and laurel (*Cordia alliodora*), though Rosero and Gewald (1979) report that the growth of laurel slows down in molasses grass (*Melinis minutiflora*) pastures.

One system described by Combe (1979) is in the highland (1200—2400 m altitude) dairying area of Costa Rica where annual rainfall is 3500 mm. An alder (*Alnus acuminata*) is planted at spacings of 7 × 9 m to 10 × 14 m. Kikuyu grass (*Pennisetum clandestinum*) is planted under the trees in 0.3-ha paddocks and rotationally grazed at 20—30-day intervals by Holstein dairy cattle that are fed concentrates. One of the advantages of using the alder is that its roots are able to fix nitrogen through the agency of a soil organism (*Actinomyces alni*). According to the data provided by Combe (1979), stocking is at the rate of approximately six to eight milking cows per ha, but this data must be suspect unless very large quantities of concentrates are fed. Combe also stated that as an alternative to grazing Kikuyu grass the forage grasses *Pennisetum purpureum* and *Axonopus scoparius* are grown under the trees and cut for feeding to the cattle.

Bishop (1979) has described a particularly productive integrated system in that area of the Amazon region of Ecuador that is located at 600 m altitude with average rainfall of 2000 mm per annum. In areas where the forest has been felled and the sown pasture has deteriorated, velvet bean (*Mucuna pruriens* var. *utiles*) is sown at the beginning of the wet season at the rate of 40—50 kg of seed per ha. In the following dry season the

velvet bean seed is harvested producing 400–500 kg per ha, and the area is then grazed. At the beginning of the second rainy season *Koronovia* grass (*Brachiaria humidicola*) is planted vegetatively at 1 × 1 m intervals together with stakes of laurel (*Cordia alliodora*) at 5 × 5 m spacing (400 per ha). The area is not grazed for one year and at the end of this year the laurel trees should be 3 m high. At this stage grazing commences at a stocking rate of two cattle per ha. At the end of the third year the stand of laurel is thinned to 200 trees per ha and at the end of the fifth year to 100 trees per ha. After 20 years the mature trees are harvested (Fig. 3). Bishop (1979) estimated that one hectare of forest produces 10 mature cattle and 100 m<sup>3</sup> of timber, as well as tree thinnings, in every 20-year cycle. Thus cattle productivity in this system is of the order of 250 kg liveweight per ha per annum.

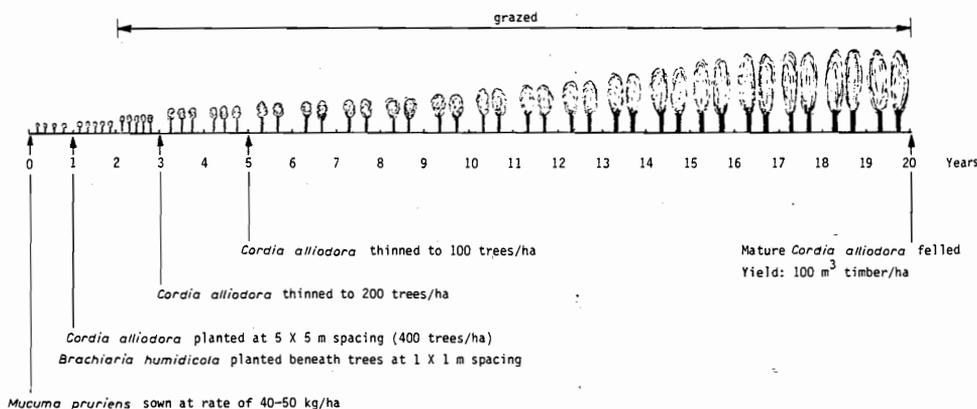


Fig. 3. Diagrammatic illustration of an integrated timber tree/cattle system in the Amazon region of Ecuador, after Bishop (1979).

There is considerable interest in cattle/timber tree systems in tropical Oceania, with projects in Queensland, Australia, the Solomon Islands, Fiji, Western Samoa and Tonga.

In Fiji, a country that is rapidly developing extensive *Pinus caribaea* forests on open hill land grazings, investigations are being made into the possibility of integrating cattle with pine tree production. A *Pinus caribaea* var. *hondurensis* forest established in 1961/62 with 1330 trees per ha and thinned after 6 to 9 years to 740 and 500 trees per ha, respectively, was stocked with crossbred (*Bos taurus* × *Bos indicus*) cattle at the rate of one l.s.u. per ha (Gregor, 1973). The area was rotationally grazed (two weeks grazing in every eight weeks); the forage under the trees consisting of various associations of *Pennisetum polystachon*, *Miscanthus floridulus*, *Brachiaria milliformis*, *Brachiaria decumbens*, *Dichanthium caricosum*, *Centrosema pubescens*, and *Desmodium heterophyllum*. The first results suggest that cattle productivity in this system is at the rate of 90 kg liveweight per ha per annum.

Possibly the most interesting project in tropical Oceania is on Kolombangam Island in the Western Province of the Solomon Islands. Initially 2600 ha of cut-over forest are being replanted with *Eucalyptus deglupta* at  $10 \times 3$  m spacing with Koronovia grass (*Brachiaria humidicola*) or Batiki blue grass (*Ischaemum aristatum*) planted between the young trees, followed by the legumes centro (*Centrosema pubescens*) or puero (*Pueraria phaseoloides*). The initial stocking rate has been 1.2 l.s.u. per ha. The growth of the trees has been most rapid in the areas grazed by the cattle and this is probably due to the fact that the cattle completely control the problem weed vine *Merremia* spp. Labour demand has been 20 man-day per ha during the first year of operations and 3 man-days per ha thereafter. On balance the forestry authorities consider that labour demand is lower than it would be if no cattle were included in the system. Cattle productivity has initially been at the rate of 200 kg liveweight gain per ha per annum. If the initial project is eventually considered to be successful then 6000 ha of cattle/forestry operations will be established on the island and private farmers will be encouraged to establish the system on their lands.

There is also considerable interest in cattle/timber tree systems in the wetter regions of tropical Africa and Asia, but to date little data on these systems has been published. In the densely populated regions of Southeast Asia there is some emphasis on systems in which forage grown under the trees is cut and fed to housed cattle. For example, Wangsudiidjaja (1980), discussing a system established on 50% slopes on a volcano in central Java, stated that *Pinus merkassi* and *Albizia falcataria* trees are underplanted with *Pennisetum purpureum* at  $0.8 \times 0.8$  m spacing, the grass being cut and carried to cattle.

To summarise, cattle/timber tree systems are already well established in the Americas and there is considerable interest in these systems elsewhere in the wetter tropics. Coniferous or broadleaved forest trees species can be used and specific spacing of the trees to encourage maximum production of forage is desirable. Cattle productivity under these grazing conditions would appear to be within the range of 100–250 kg of liveweight gain per ha per annum. Where there is a dense human population cut and carry managerial systems may be economic.

#### *The drier regions of the tropics*

It has been stated in a previous section that it has been traditional practice to graze cattle under trees in some of the drier regions of the tropics, but that the ecosystems involved are fragile and in general are being degraded by overstocking and continuous firing. There are, therefore, many attempts being made to reverse this situation, particularly in Africa.

For example, at Baringo in Kenya there is a large area of somewhat flat, fertile alluvial soils around Lake Baringo, that receives on average 650–700 mm of very seasonal rainfall per annum, the duration of the

dry season being six or seven months. The area was originally open dryland forest with a groundcover of grasses and bushes, but it has been almost completely denuded of ground cover on account of overstocking and the mature trees are decreasing in number as they are increasingly lopped to provide forage during the season and seedling trees are destroyed by the livestock and fire. At present the World Bank are financing a locally administered integrated project, one objective being to improve the degraded vegetative cover. This is being accomplished by enclosing areas using thorn fences, and within the enclosed areas constructing with hand hoes approximately 10–15 m long, 20 cm high semi-circular ridges with the semi-circle extending down the slight slope of the land. These ridges dam up some rain that would otherwise run-off and after one season of enclosure there is a considerable cover of self seeded grasses, mainly *Eragrostis superba*. In some of the semi-circular ridges a small hole is dug at the centre of the semi-circle and indigenous legume trees such as *Balanites aegyptica* and *Acacia melifera* together with some exotic species are planted. This procedure appears to be a very cheap and effective way of regenerating the vegetative cover but of course it does not solve the problem of overstocking.

There is considerable controversy amongst livestock owners and advisers as to whether it is desirable to include trees in dryland grazings. The trees undoubtedly compete with ground forage species in the dry season for available water, thus reducing the quantity and quality of ground forage available, but at the same time they improve fertility by bringing mineral nutrients from deep soil into a cycle that makes them available in shallow soil to the ground forage species, and if the trees are legumes they enrich the soil with nitrogen. Trees also provide shade for cattle, fence posts and timber for constructing yards, etc. and high quality browse in the dry season. It is possible in low input/low output ranching systems, particularly in regions in which heat stress is not too severe, that trees are not as useful as they are in higher input/higher output labour intensive systems.

Loján (1979) has described an integrated system used in the dry forests of Ecuador, located at 1800–3000 m altitude, in areas where the dry season lasts from June to December. Whatever the state of the forest, all except commercially valuable trees are cut and the debris burnt at the end of the dry season. The species retained are laurel de cerca (*Myrica pulercens*), cashco (*Weimania* spp.), robles (*Poupala* spp.), canelas (*Ocotea* spp.; *Persea* spp.), romerillo (*Podocarpus* spp.), cedro (*Cedrela montana*), arrayanes (*Eugenia* spp.) and cascarilla (*Cinchona* spp.). The grass *Olcus lanatus* is sown after the burn and regrowth of cut vegetation controlled by herbicides. At first the fern *Pteridium aquilinum* proliferates. This is partially controlled by hand weeding. Cattle are introduced as soon as sufficient ground forage is available and they spread Kikuyu grass (*Pennisetum clandestinum*) from adjacent pastures through the medium of their faeces. Two or three years after the introduction of the cattle there is a close sward of Kikuyu grass under the trees. Unfortunately, Loján does not provide any data as to the productivity of this system.

An attempt to create a cattle/timber tree system in the relatively dry southern highland region of Ecuador has also been described by Loján. *Eucalyptus globulus* is planted at 2 x 3 m spacing and some Kikuyu grass (*Pennisetum clandestinum*) is planted between the trees in the wet season. For the first two or three years the area is grazed by sheep as cattle damage the young trees. Once the trees are of sufficient height to escape damage, cattle are introduced and they spread the Kikuyu grass through the medium of their faeces. Loján noted that there was competition for water during the dry season and that the pasture dried out, so that stocking rates could not be very high. He also noted that a fern, *Pteridium aquilinum* that grew in the area, if eaten caused haematuria in the cattle. He further suggested that in hot regions of lower rainfall the mesquite (*Prosopis juliflora*) and faique (*Acacia manacanther*) were trees of particular value for cattle/tree crop systems.

It would appear from the available literature that there has been less investigation of cattle/timber tree systems in the drier than in the wetter regions of the tropics, despite the fact that the system is traditional in some drier regions. Cattle productivity is undoubtedly far less in the drier than in the wetter region systems.

#### CATTLE/NUT, FRUIT AND INDUSTRIAL TREE CROP SYSTEMS

##### *The wetter regions of the tropics*

The most important cattle/tree crop system in this category is the cattle/coconut system, only viable in the wetter regions of the tropics. Other nut, fruit and industrial tree crops that might be used, are oil palm, rubber and many species of tropical fruit.

##### *Cattle/coconut systems*

Child (1974) estimated that the world area of coconut palms was approximately 6 million ha in 1971 and that more than 90% of the total area was in Asia and Oceania. This estimate included areas where total rainfall is less than 2000 mm or is seasonally poorly distributed, where the soils are heavy or poorly drained and where dwarf varieties, unsuitable for cattle/coconut operations, are planted. Payne (1976) estimated that the area planted to coconuts in the humid tropics, suitable for cattle/coconut operations was approximately 4.5 million ha. However, it is now obvious from data provided by the Fats and Oil Team, FAO (1979) that the areas of coconuts in the Philippines and Indonesia were underestimated by Payne (1976) and that during the last ten years there has been a considerable increase in the area planted to coconuts in these countries. The data available (Fats and Oil Team, FAO, 1979) suggest that in 1979 the total area of coconuts in the world was approximately 7.2 million ha, of which area 46% was in the Philippines and 78% in the Asian continent.

It is now estimated that the area of coconuts in the humid tropics suitable for cattle/coconut operations may be of the order of 6.0 million ha.

*The present extent of cattle/coconut systems.* Detailed information on the present extent of cattle/coconut systems is very limited. In the Philippines, where 46% of the world's coconuts are grown, Barker and Nyberg (1968) surveyed 1230 farms and found that on 22% cattle were grazed under the coconuts. They also reported that 52% of farmers with more than 45 ha of coconuts grazed cattle, and that farms operating cattle/coconut systems were concentrated in the more humid southern islands. In Sri Lanka cattle/coconut operations are widespread in the more humid areas. In the South Pacific there has been a rapid increase in cattle/coconut grazing schemes. In Fiji, Leather (1972) reported that the majority of better-managed plantations grazed cattle under coconuts, whilst in Vanuatu the author noted that almost all cattle in the islands graze under coconuts. In Western Samoa and the Solomon Islands increasing numbers of cattle are managed under coconuts.

It is estimated that some form of cattle/coconut system is used in perhaps one sixth to one quarter of the area of coconuts suitable for such operations. The possibility therefore exists for a very large expansion of integrated cattle/coconut operations. However, there are factors operating against expansion. As the ratio of human population to land resources rises and land increases in value, higher value crops may be substituted for forage. Suitable crops for growing under coconuts are cocoa, coffee, bananas, pineapple and some other fruits, and extensive areas of these crops are already grown in some countries. In addition, the planting of dwarf varieties of coconuts is expanding particularly in those regions where the disease lethal yellowing has decimated extensive areas of tall palms. Dwarf and some hybrid palm plantations are not particularly suitable for cattle/coconut operations as the cattle are likely to damage the palms.

*Suitable forage species.* In many humid tropical countries, particularly in Asia and Oceania, when cattle or other ruminant livestock are grazed under coconuts a natural pasture develops that is dominated by the grasses *Paspalum conjugatum* or *Axonopus* spp. In those countries where the legumes *Mimosa pudica* and/or *Mimosa invisa* are indigenous or have been introduced, these may dominate the grass species. *Desmodium* spp. and *Indigofera* spp. may also be present in such pastures. For example, Queen and Foale (1961) stated that in those islands in the South Pacific where there is a high and well distributed rainfall *Paspalum conjugatum* dominates well-grazed, whilst *Mimosa* spp. dominates ungrazed pastures under coconuts.

As the livestock-carrying capacity of natural pastures is usually low and planted forage species increase cattle stocking rates and livestock gains and hence farm profits (Barker and Nyberg, 1968), investigations are being

made in many coconut growing countries to discover the most suitable forage species to grow under coconuts.

Some of the earliest investigations were made at the Coconut Research Station in Sri Lanka, where an Agrostology Division was established in 1958. The results of investigations in Sri Lanka may be summarised as follows. *Brachiaria brizantha*, *B. miliiformis*, *Digitaria decumbens* and *Panicum maximum* are all suitable grass species. *B. miliiformis* and *D. decumbens* are superior in the dry months, whilst *B. miliiformis* is more shade tolerant than the other grasses and responds better than *B. brizantha* to nitrogen fertiliser. *P. maximum* requires high fertiliser application if coconut yields are not to be depressed. *Calapogonium muconoides*, *Centrosema pubescens* and *Pueraria phaseoloides* are suitable legume species, but *C. muconoides* is not very palatable whilst *P. phaseoloides* should be used on light soils and *C. pubescens* on heavier soils (Santhirasegaram, 1966; Ferdinandez, 1973).

In southern Thailand *Brachiaria brizantha* and *Panicum maximum* have been found to be suitable grass species. It has been shown in Jamaica that replacing natural by planted pasture under tall palms growing at low density (100 per ha) increases total income per ha and that *P. maximum* is superior to *Digitaria decumbens* on poorer soils and in lower rainfall areas, but that both grasses and the coconuts require appropriate fertilisers (Coconut Industry Board, Jamaica, 1970-71). Steel and Humphreys (1974) working in Bali, Indonesia, recommended the use of the legumes *Lotononis bainesii* and *Stylosanthes guyanensis*. Hill (1969) studying cattle/coconut systems in Papua New Guinea recommended the use of *Brachiaria mutica* and *B. ruziziensis* and the legume *Leucaena leucocephala*. In the Solomon Islands the use of *Brachiaria miliiformis*, *B. ruziziensis*, *Panicum maximum* cv. Makueni and *P. maximum* cv. Petrie Green has been advocated. Reynolds (1977) considered that in the South Pacific *Brachiaria brizantha*, *B. decumbens*, *B. humidicola*, *B. miliiformis*, *Ischaemum aristatum* and *Panicum maximum* cv. Embu are suitable grasses to grow under coconuts, whilst Ranacou (1972) stated that *B. humidicola* and *I. aristatum* persist well in plantations.

There appears to be general agreement between investigators in several different countries that *Brachiaria brizantha*, *B. miliiformis* and some varieties of *Panicum maximum* are suitable grasses to grow under coconuts and it is interesting to note that these are the species that are most productive at low light intensity according to the investigations of Eriksen and Whitney (1977). There does not appear to be the same degree of uniformity with regard to opinion as to the most useful legume, but *Centrosema pubescens* appears to be used in many regions. Singh and Naidu (1973) stated that Balaga blue grass (*Ischaemum indicum*) had a detrimental effect on the growth and yield of coconut palms in Fiji.

*Application of fertilisers.* Apart from the fact that the plant nutrient needs of both the coconuts and the forage must be considered, it is difficult to

make general recommendations for fertiliser application. These will obviously vary from soil type to soil type and according to the local economic situation. If the forage is not fertilised, however, it is almost certain that there will be some decline in the yield of the coconuts, as plant nutrients are progressively removed by the sale of coconuts and animal products.

*Management of cattle.* There are indications that rotational grazing rather than set-stocking should be the preferred grazing system in cattle/coconut systems. Rotational grazing is strongly advocated in the Philippines and there is some experimental evidence from the Solomon Islands that set-stocking reduces the grass component of mixed pastures. This appears to be due to the fact that grasses lose their competitive growth advantage over legumes under shade, due to a relatively greater reduction in photosynthesis (Watson, 1977; Whiteman, 1977). A decision as to which grazing system to use also depends to some extent upon the grass species planted. If *Panicum maximum* is used, rapid rotational grazing is preferable, as overgrazing of this palatable bunch grass can quickly destroy the stand. In plantations where nuts are allowed to fall to the ground and are picked up at some later date, there is another valid argument in favour of rotational grazing. This is, that one of the advantages of grazing cattle under coconuts is that they keep the ground vegetation short, thus helping to ensure a high nut pick-up percentage. For example, in the Solomon Islands it has been shown that grazing with cattle ensures that the nut pick-up increases from 75 to 90% of the total crop. Rotating the cattle in front of the pick-up labour, so that the forage crop is grazed as short as possible immediately before nut collection, obviously assists in ensuring a high pick-up percentage. The construction of fences in cattle/coconut systems should also be less costly than it is in many other systems, as growing trees can be used as fence posts (also treated, old coconut trunks make excellent posts), and as cattle/coconut systems are only viable in humid areas the erection of cheap live fencing is possible.

The provision of adequate water supplies for the cattle is as important as it is elsewhere, as is the provision of suitable mineral feeds.

As cattle can severely damage young coconut palms — indeed, coconut leaves appear to be very palatable — plantations should not be grazed until the terminal growing point and most of the leaves of the young palms are above the heads of the cattle. Under good managerial conditions this means that cattle should not be grazed in young palms for approximately the first 4–5 years after planting. On small farms individual palm trees may be fenced against cattle. The use of repellents on young palms has been investigated in some countries. In Sri Lanka some success has been claimed where cattle dung slurry has been sprayed on young palms to act as a repellent.

As there is some amelioration of climatic stress on cattle grazed under coconut palms it should be possible and economic to use higher grade

and possibly more productive cattle in cattle/coconut systems than could be used in open grazing systems. This situation could be exploited more than it is at the present time for the production of milk, as milk production from dairy cattle is more adversely affected by climatic stress than is the growth of beef cattle. It should also be possible to manage higher grade and thus probably more productive *Bos taurus* × *Bos indicus* beef cattle in cattle/coconut systems.

*Stocking rates.* These will depend upon the forage species utilised, the degree of shading, the soil fertility, fertiliser inputs and the overall management of the forage and the cattle. The data available suggests that under good managerial conditions stocking rates may vary from 1.5 to 3.0 l.s.u. per ha (Hill, 1969; Ohler, 1969; Reynolds, 1977; Whiteman, 1977).

*General recommendations.* Cattle/coconut systems may be easily established in those regions where total annual rainfall is 2000 mm or more and is seasonally well distributed. Conditions may not be so suitable in regions receiving less rain. The soils should be well drained. Tall coconut varieties should be planted at optimal spacing for maximum nut yield and productive, shade tolerant forage species should be undersown. Fertiliser application to palms and forage plants is usually essential in the long term.

Productive cattle should be rotationally grazed beneath the trees once they are of sufficient height. The stocking rate should be adjusted on a year-round basis to maintain the grass/legume balance in the forage mixture and maximum productivity. Adequate supplies of water and minerals should be available for the cattle.

#### *Cattle/oil palm systems*

Oil palms are normally planted on a triangular 7.5–10.0 m spacing (115–205 palms per ha). Cropping begins 4–5 years after planting and continues until the palms are 25–30 years old (Fig. 4). At this time the palms are either too tall for easy harvesting or the yield is no longer economic. Usually mixtures of legumes, such as *Centrosema pubescens*, *Stylosanthes* spp. and *Calapogonium muconoides* are sown between the young palms. A canopy forms when the palms are about eight years old, but there is still sufficient light at ground level for some vegetation to grow.

Cattle should not be introduced until three years after the palms have been planted as they are liable to damage the young trees. After the third year cattle can be grazed between and under the trees (Fig. 4), but after the eighth year the canopy normally closes and the quantity of forage available rapidly declines. It would be advantageous if cattle grazed between and beneath the trees could also be fed some part of the by-products of oil palm extraction. These are empty bunches, sludge, wet fibre and oil palm kernel cake, being 25, 11, 13 and 2%, respectively, of the original weight of fresh fruit. The oil palm kernel cake could be fed to productive milking

cattle and the sludge and wet fibre are potential low quality feeds for beef cattle. The empty bunches can be used as a fuel.

Major problems associated with the management of cattle/oil palm systems are:

- protection of the young palms during the first three years of their life;
- the planting of suitable forage crops between the young palms;
- the most suitable spacing of the palms; and
- the most suitable method of managing the cattle in order to utilise most economically the fluctuating forage supply.

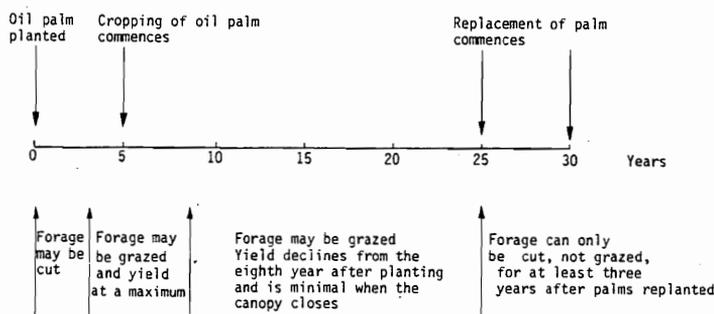


Fig. 4. Diagrammatic representation of a livestock/oil palm system.

Cattle/oil palm systems have been investigated in West Africa, where, on account of the fact that most oil palm plantations are located in tsetse fly infested areas, the choice of cattle is limited to trypanotolerant breeds such as the Maturu and the N'dama. The system is also practised in Southeast Asia, where there has been some limited investigational work. In tropical America, many oil palm plantations have been established in former ranching areas. These easily become infested with grasses such as *Hyparrhenia rufa*, and the introduction of cattle into these plantations appears to be a rational method of controlling the grass. Hartley (1977) considered that cattle/oil palm systems have been successful in tropical America, particularly in Colombia, where stocking rates have been low (0.5 l.s.u. per ha) and rotational grazing practised, but that they cannot be recommended in many areas due to lack of control of the cattle and a preponderance of heavy soils on which the continuous treading of cattle impedes drainage, reducing oil palm yields. Thomas (1978) also stated that cattle can cause damage in tropical America, where heavy textured soils and high water tables are to some extent characteristic of oil palm plantations.

In order to protect oil palms during the first three years of their life, land between them can be cropped and no forage planted until the third year, or if forage is planted it can be cut and fed to cattle managed elsewhere or it can be grazed by sheep. Electric fencing can be used to protect young palms from cattle grazing elsewhere in the plantation.

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Neither conventional leguminous cover crops nor indigenous forage plants are usually satisfactory as sources of forage in oil palm plantations. Leguminous cover crops are too easily 'grazed out' as the canopy develops, and indigenous forage crops are usually low-yielding. Forage species that grow well in coconut plantations also grow well in oil palm plantations, though shade is denser in the latter as the canopy forms. In young plantations mixtures of *Panicum maximum* and *Centrosema pubescens* may be satisfactory whilst in older plantations mixtures of *Desmodium* spp. with *Axonopus compressus* and *Paspalum conjugatum* may be more suitable. In West Africa the fodder grass *Pennisetum purpureum* has been used. Hartley (1977) stated that in the first three years its growth must be restricted or else it reduces the growth of the palms, whilst by the 10–12th year it is shaded out and completely disappears.

In West Africa there has been investigation of the most suitable spacing of palms in cattle/oil palm systems. Hartley (1977) reported that in a spacing investigation in Nigeria it was found that *P. purpureum* grew better and persisted when the palms were spaced rectangularly, without appreciable loss in fruit yield. At  $6.4 \times 12.8$  m rectangular spacing (128 trees per ha) fruit yield was 6.9 tonnes per ha, whilst at 9.1 m triangular spacing (138 trees per ha) it was 7.6 tonnes per ha. The carrying capacity of the rectangularly spaced palms grazed by N'dama cattle was 1.2 l.s.u. per ha and plantation maintenance costs were reduced. Rombaut (1974) reported that in the Ivory Coast Baoulé cattle managed in palm oil plantations at a stocking rate of 0.5 l.s.u. per ha gained 0.5 kg liveweight per day. In Malaysia, Obisara (1970) stated that 210 cattle (including 70 breeding cows) could be managed in a 100 ha plantation if rotational grazing was used and that there was a saving on weeding costs, but that cattle could cause damage to the drainage system. The stocking rate quoted by Obisara appears high and it is not clear from his data whether this was the rate only from the third to the eighth year or for a mature plantation.

The most difficult managerial problem in cattle/oil palm systems is undoubtedly fluctuation in the quantity of forage available from year to year. For approximately five years, from the third to the eighth year, there is probably 3–6 times as much forage available per unit area per year as there will be in the following 20 years. In large plantations this problem can be overcome by planting approximately one fifth of the total area each year, so that the total quantity of forage available in the whole plantation does not fluctuate too widely from year to year. In smaller plantations it is necessary to devise some other method by which cattle numbers can be allowed to fluctuate from year to year. This can be accomplished through the cooperation of small plantation owners or by some form of government intervention as cattle herds managed outside the plantations are required in order to operate a 'put and take' stocking policy in the plantations.

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### Cattle/rubber tree systems

The possibility of using forage available in rubber plantations has generally been ignored, though a few smallholders and labourers on plantations in Southeast Asia herd livestock under rubber trees. However, the inherent difficulties of integrating livestock and rubber production have to date prevented any large scale action. These inherent difficulties are that the quantity of forage available fluctuates as trees in the plantation mature (Fig. 5); young trees have to be protected from damage as have the latex collection cups on mature trees; and few efforts have yet been made to select suitable forage plants for the rubber plantation environment.

It has been calculated that the average quantity of forage available annually throughout the life of the plantation would be approximately 40% of the total available during the first year, but the quantity varies widely from year to year (Fig. 5). The problem of utilising a fluctuating forage production could be solved by the adjustment or lease-lending of cattle to small rubber farmers by cooperative or government organisations and by large plantations organising their own ranches in order to provide cattle when they are required. The problem of preventing damage is more difficult to solve. Cattle could be carefully herded or forage could be cut and fed to them; both relatively expensive operations for large growers but not for smallholders. Lowe (1968, 1969) has suggested that the most useful livestock to use in rubber plantations would be sheep rather than cattle.

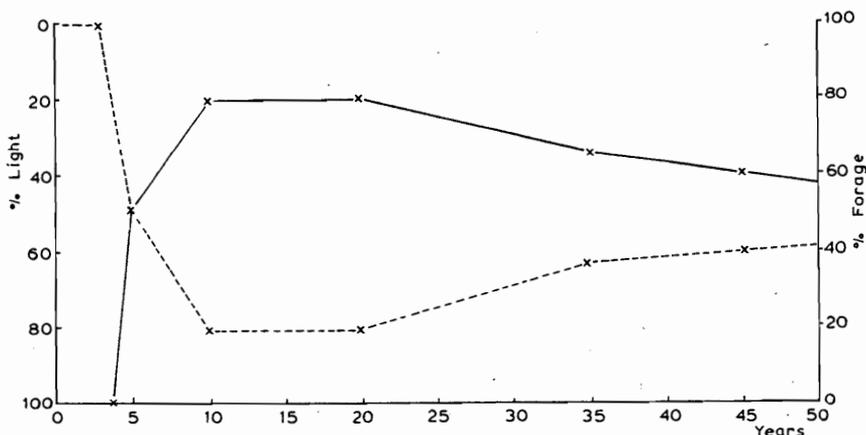


Fig. 5. Diagrammatic representation of the availability of forage in a rubber plantation; x—x, estimated percentage of light reaching the ground; x-----x, estimated quantity of forage available as percentage of forage available on open land under similar conditions.

Although mixtures of legume species are often used for interplanting between young rubber trees, these tend to die out as the canopy closes, and in most rubber plantations in Southeast Asia the vegetation beneath mature trees consists of self sown species such asalang (*Imperata cylindrica*), Siam weed (*Eupatorium odoratum*), *Mimosa pudica*, and possibly grasses

such as *Axonopus compressus*. Lowe (1968) mentions some advantages of the system over and above the production of meat as well as rubber. The first is that grasses grown in the shade have a higher nitrogen content and are consequently more nutritious than the same grasses grown in the open. He provides the following data to support this statement:

Grass	% Nitrogen in grass	
	Open pasture	Under rubber tree shade
<i>Brachiaria mutica</i>	2.26	2.67
<i>Axonopus compressus</i>	1.71	2.28

The second is that air temperatures above the ground in broken shade are 1–2°C less than in open sunlight, so that heat stress on livestock is somewhat ameliorated and their appetite is improved. Further integration can be achieved by the feeding of the by-product rubber seed meal, that contains 23–31% crude protein, to livestock managed under rubber trees.

#### *Cattle/fruit tree systems*

There is little investigational data available with regard to these systems, but throughout the wetter tropics forage species are planted or grow naturally under fruit trees and frequently are either cut and fed to livestock or are grazed. The low mature height of some tropical fruit trees and the risk of damage to the fruit often precludes the use of mature cattle for grazing purposes, but forage from beneath or between the trees can be cut for feeding to cattle elsewhere. Reategui (1979) stated that in the Amazonian region of Peru farmers plant the legumes pueru (*Pueraria phaseoloides*) and centro (*Centrosema pubescens*) under fruit trees such as *Citrus* spp., avocado (*Persea americana*) and guava (*Psidium guajava*), and suggested that with the addition of a grass such as *Brachiaria decumbens* to the forage legumes an integrated cattle/fruit tree system could be established.

Prentice (1979) stated that in the upper region of Ecuadorian Amazon (altitude 600–1000 m; annual rainfall 4500–6000 mm), ranches developed from the rainforest using the grass *Axonopus scoparius* have a productive life of only 5–20 years and that after this period they are abandoned. Investigations on the rehabilitation of these exhausted lands are proceeding at an experimental centre in the region. The establishment of a cattle/poultry/fruit tree crop system is being investigated as one rehabilitation possibility. Forage is grown under suitable fruit trees, poultry are managed at free range under the trees during the day and housed at night, whilst the forage is cut daily and stallfed to Holstein X Criollo milking cows. The major fruit trees used in this system are banana and plantain (*Musa* spp.), *Rollinia* spp., breadfruit (*Artocarpus altilis*) and guava. In addition pineapple is grown as a field crop. The major forage species grown under the trees is *Axonopus scoparius*. Prentice further stated that the poultry

and cattle manure are used to fertilise the fruit trees, that *Axonopus scoparius* is more productive when cut than when grazed and that the free range poultry help to control weeds in the pineapple crop. Unfortunately no data on productivity are provided.

#### *The drier regions of the tropics*

Cattle/tree crop systems of this type are relatively unimportant in the drier regions of the tropics, though there are isolated examples of cattle grazed under cashew nut trees or fruit trees such as mangoes, or of forage grown under trees being cut in the wet season to feed to cattle.

This system is more likely to be practised where the trees are irrigated. One example may be seen adjacent to the Nile in the Northern Province of the Sudan. Lucerne (*Medicago sativa*) is grown under irrigated date palms and regularly cut for feeding to livestock; particularly dairy cattle. In this region lucerne grown on open land quickly becomes infested with weeds, in particular the grass known locally as halfa (*Imperata cylindrica*), whilst under the shade of the palms weed infestation is markedly decreased. The date palms are considered to benefit from the fixation of nitrogen by the lucerne crop.

#### BROWZING OR HARVESTING OF TREE FORAGE

##### *The wetter regions of the tropics*

The foliage of forage trees is casually browsed by cattle in many wetter regions of the tropics and in areas with dense human and livestock populations the foliage of forage trees may be systematically harvested and stallfed to cattle. There are many areas, particularly in South and Southeast Asia, where this system is practised; a classical example occurring in the island of Madura.

Madura is situated a short distance off the north coast of Java, Indonesia. The total land area of the island is 4497 km<sup>2</sup>, the total annual rainfall varies from 1500–2000 mm per annum and the length of the dry season from 2–5 months, according to location. In 1971 the human population was 2.4 million, with an overall density of 530 head per square km and an annual growth rate of one percent. This growth rate is substantially less than that of the remainder of Indonesia, due to migration. The indigenous rain forest was destroyed at least 150 years ago and crops now occupy 88% of the total land area of the island. No forage crops are grown on the cropped land. There are no permanent pastures, though small areas of rough grazing still exist as do 25 000 ha of degraded forest.

Despite the very dry conditions that exist during part of the year, the small size of the average holding (0.57–0.75 ha, according to location) and the complete absence of cultivated fodder crops and pastures, farmers

on Madura maintained approximately 560 000 cattle, 8000 buffalo, 21 000 sheep and 125 000 goats during the period 1962-71.

This extraordinary situation is only possible because the average farmer is an excellent animal husbandman, who uses crop residues, crop by-products and large quantities of browse and fallen leaf material to feed his animals and discounts the cost of family labour needed to continuously gather forage.

Cattle are usually continuously housed in substantial buildings, though at certain seasons mature females and young animals may be tethered on roadsides and field bunds for part of the day. The basic ration of cattle is cut forage. Approximately 25-30 kg are required daily for each adult animal and the average farm family spends two to three hours each day cutting and carrying this quantity. During the wet season short grasses and herbs cut from roadsides and bunds supplement legume tree forage, but during the dry season supplies are not available and in addition to highly nutritious leguminous browse the farmer is forced to feed the leaves of garden fruit trees such as mango and jackfruit (*Artocarpus integrifolia*) and any other vegetative material available such as dry coconut fronds, bamboo leaves and forage from *Pinus merkussi*. The major legume forage tree used in this system is *turi* (*Sesbania grandifolia*), planted on field bunds and roadsides. *Lamtoro* (*Leucaena leucocephala*), growing in more limited quantities, particularly in rocky outcrop areas, is also used. A smaller supply of legume forage is obtained from *Gliricidia sepium* and *Acacia* spp..

*Sesbania grandiflora*, the major legume forage tree utilised, grows exceptionally quickly, both from seedlings and after lopping, provides light shade under which ground forage plants thrive and its young leaves, tender pods and large white flowers are exceptionally nutritious. Young leaves contain up to 36% crude protein and possess a high mineral and vitamin content (National Research Council, 1979).

Madura cattle are remarkably uniform in type and are possibly derived from ancient crossbreds between Javanese type cattle (*Bos taurus* × *Bos indicus*) and the wild banteng (*Bos (bibos) banteng*) (Payne and Rollinson, 1976). They are of medium size, possessing a fairly compact body and moderately long legs. The importation of other breeds into Madura is normally prohibited but an exception was made in the late 1940s when Red Danish cattle were introduced for crossbreeding purposes and an unsuccessful effort was made to develop a dairy industry using crossbred cattle. Madura cattle are normally bred for *kerepan sapi* or bull racing, a sport unique to Madura, and are used for work purposes and for meat production; a considerable number of bull calves and yearling bulls being exported to Java where they are raised and fattened (Payne and Rollinson, 1976).

The average herd size is small, the majority of farmers owning only one or two cattle. As with other breeds apparently possessing genes derived from the banteng, the reproductive performance of Madura cattle is relatively good. The calving rate is about 75% with heifers first calving at around

three years of age when they weigh approximately 150–160 kg. Milk production of cows is very low; estimated to be of the order of 0.5 kg per day. Growth is slow, bulls maturing at 300–340 kg liveweight at six years of age, though they are normally slaughtered at four and one half to five years of age when they weigh 240–280 kg. The commercial offtake from this low input system is surprisingly high; varying between 16–22% per annum between 1952 and 1971 (Payne and Rollinson, 1976).

The Madura system of feeding cattle on large quantities of tree forage has been described in some detail, not only because it is an unique and interesting system, but also because it demonstrates possible achievement. It is a system, however, that is totally dependent upon cheap family labour and similar results could only be attained in those areas of the wetter tropics in which the same economic and social conditions exist.

It is suggested that it should be possible to devise cattle/tree crop systems not completely dependent upon cheap family labour, that can more economically exploit tree forage and particularly legume tree forage resources in the wetter regions of the tropics, and that this would be a promising sector for detailed investigation. *Sesbania grandiflora* is a particularly valuable legume forage tree, almost unknown outside Southeast Asia, and its potential could be more fully exploited; but there are many other trees in the wetter tropics, with a somewhat similar potential, that would repay study. The use of *Leucaena leucocephala* is already widely advocated and this plant is at present the subject of considerable study throughout the tropics.

#### *The drier regions of the tropics*

Browse is an essential element in the diet of cattle during the dry season in many regions of the drier tropics. It has been shown in Senegal (Blancou et al., 1977) that during the dry season an average of 25% of total cattle feed intake is browse and that the proportion increases from 5% at the beginning to 45% at the end of the dry season. It has also been stated (National Research Council, 1979) that in the Brazilian savanna cattle obtain approximately 60% of their forage intake from leguminous trees and shrubs

TABLE 3

A comparison of the feeding values of dry standing grass and fresh browse during the dry season in the Sahel

	Net energy (Kcal/kg DM)	Dig. Protein (% DM)	Phosphorus (g/kg DM)	Calcium (g/kg DM)	Carotene (mg/kg)
Dry standing grass	600–800	<3	<1	1.5– 3.0	<1
Fresh browse	400–700	5–30	1.5–2.5	2.5–20.0	50–800

Source: Le Houérou (1978).

during the six months dry season. Green, nutritious browse is available long after other forage has completely dried out or has been consumed, and as can be seen from Table 3, browse usually possesses a higher content of nutrients, particularly digestible protein and some essential minerals, than most of the available ground forage. Apart from green foliage, trees and bushes may provide seed pods, seeds and dried foliage, and these are often the only feeds available for cattle at the end of the dry season in dryland forest, savanna and thornbush areas. The seed pods of legume trees and bushes possess a relatively high nutrient content (100–2000 Kcal per kg dry matter and 10–20% digestible protein).

Some of the more useful browse plants used in the drier regions of Africa, the Americas, Asia and Oceania are as follows:

*Africa.* In the arid, semi-arid and sub-humid climatic zones of Africa *Acacia* spp. are of particular importance as browsing plants, but many other species are also useful, and some of these are listed in Table 4.

TABLE 4

Some useful browse species in tropical Africa

Family	Genus and species	Family	Genus and species
Anacardiaceae	<i>Lannea acida</i> <i>Sclerocarya birrea</i>	(Mimosoideae)	<i>Acacia flava</i> <i>Acacia giraffea</i> <i>Acacia laeta</i> <i>Acacia mellifera</i> <i>Acacia senegal</i> <i>Acacia seyal</i> <i>Acacia sieberiana</i> <i>Acacia tortilis</i> <i>Albizzia amara</i> <i>Dichrostachys cinerea</i> <i>Entada africana</i> <i>Prosopis africana</i>
Balanitaceae	<i>Balanites aegyptiaca</i> <i>Balanites glabra</i> <i>Balanites rotundifolia</i>		
Caesalpiniaceae	<i>Bauhinia rufesens</i> <i>Tamarindus indicus</i>		
Capparaceae	<i>Cadaba farinosa</i> <i>Cadaba glandulosa</i> <i>Capparis decidua</i>		
Capparidaceae	<i>Boscia albitrunea</i> <i>Boscia angustifolia</i> <i>Boscia senegalensis</i> <i>Maerua angolensis</i> <i>Maerua crassifolia</i>	Papilionaceae	<i>Dalbergia melanoxylon</i> <i>Pterocarpus lucens</i>
		Rhamnaceae	<i>Ziziphus mauritiana</i>
Combretaceae	<i>Anogeissus leiocarpus</i> <i>Combretum aculeatum</i> <i>Terminalia brownii</i>	Rubiaceae	<i>Feretia apodanthera</i> <i>Mitragyna inermis</i>
		Salvadoraceae	<i>Salvadora persica</i>
Mimosoideae	<i>Acacia albida</i> <i>Acacia bussei</i> <i>Acacia cyanophylla</i> <i>Acacia etbaica</i> <i>Acacia ehrenbergiana</i>	Sterculiaceae	<i>Sterculia setigera</i>
		Tiliaceae	<i>Grewia bicolor</i> <i>Grewia tenax</i> <i>Grewia villosa</i>

TABLE 5

A limited selection of particularly useful browse species

Botanical name	Description	Climatic environment, comments
<b>Wetter regions</b>		
<i>Desmodium discolor</i>	Shrub, 3 m	Subtropics; 1000–1500 mm rainfall
<i>Desmodium gyroides</i>	Bush, 4 m	Tropics; >1000 mm rainfall; tolerates water logged soils
<i>Desmodium nicaraguense</i>	Shrub, 6 m	Tropics; >1000 mm rainfall
<i>Sesbania grandiflora</i>	Tree, 5–8 m	Humid tropics; >1000 mm rainfall
<b>Wet and dry regions</b>		
<i>Desmanthus virgatus</i>	Bush, 2–3 m	Tropics; >800 mm rainfall; tolerant of heavy grazing
<i>Desmodium distortum</i>	Bush, 2 m	Tropics; >800 mm; useful on acid soils
<i>Leucaena leucocephala</i>	Small tree, 4–5 m	Tropics; >600 mm rainfall; tolerant of alkaline soils; contains mimosine, toxic to livestock under certain conditions; low mimosine cultivars are being developed by CSIRO in Australia
<b>Drier regions</b>		
<i>Acacia albida</i>	Tree, up to 30 m	Tropical Africa; >650 mm rainfall; but will grow in areas with rainfall >300 mm if underground water available; usually found below 1600 m altitude
<i>Acacia aneura</i>	Tree, 8 m	Tropics and subtropics; 200–500 mm rainfall
<i>Acacia pendula</i>	Tree, 6–12 m	Tropics and subtropics; 400–500 mm rainfall
<i>Acacia senegal</i>		
<i>A. senegal</i> var. <i>senegal</i>	Tree, <12 m	Tropics; 200–350 mm rainfall; yields well on poor sandy soils; a source of gum arabic
<i>A. senegal</i> var. <i>kerensis</i>	Shrub, 3–4 m	
<i>Acacia seyal</i>	Small tree, 3–6 m	Tropics; 500–800 mm rainfall; grows particularly well on black cotton soils
<i>Acacia tortilis</i>	Tree, 4–20 m	Tropics; 100–1000 mm rainfall, grows on edge of desert where pods provide major feed for livestock; also provides forage and firewood
<i>Acacia victoriae</i>	Shrub, 2–3 m	Tropics and subtropics; >500 mm rainfall
<i>Atriplex nummularia</i>	Bush, 1–2 m	Tropics and subtropics; 200–800 mm rainfall; withstands heavy grazing
<i>Atriplex repens</i>	Small shrub	Tropics and subtropics; 200–800 mm rainfall
<i>Balanites aegyptiaca</i>	Tree, 6–12 m	Tropics; 500–1000 mm rainfall; produces forage for cutting and a fruit used by many peoples; also useful timber; common on black cotton soils

(continued)

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TABLE 5 (cont.)

Botanical name	Description	Climatic environment, comments
<i>Cassia sturtii</i>	Shrub, 2 m	Tropics and subtropics; 200–250 mm rainfall; does best on loamy soils
<i>Opuntia</i> spp. <sup>a</sup>	Shrub, 1–3 m	Tropics and subtropics; <300 mm rainfall; only spineless varieties suitable as forage
<i>Prosopis affinis</i>	Tree, 2–8 m	Subtropics; >500 mm rainfall
<i>Prosopis alba</i>	Tree, 5–15 m	Subtropics; 250–500 mm rainfall
<i>Prosopis chilensis</i>	Tree, 8–12 m	Subtropics, but will grow up to altitude of 3000 m; 250–500 mm rainfall
<i>Prosopis nigra</i>	Tree, 4–10 m	Subtropics; 250–500 mm rainfall
<i>Prosopis pallida</i>	Tree, 8–20 m	Tropics; >500 mm rainfall
<i>Prosopis tamarugo</i>	Tree, up to 18 m	Tropics and subtropics; 100–200 mm rainfall; will grow on arid salt flats
<i>Prosopis juliflora</i> var. <i>velutina</i>	Tree, up to 10 m	Tropics and subtropics; 150–750 mm rainfall; grows on poor sandy soil; pods (17 % CP) yield up to 20 t/ha; flowers a good source of nectar for bees

<sup>a</sup>The major cultivated forms are: *O. ellisiana*, *O. ficus indica* (grown in N.E. Brazil on a large scale) and *O. inermis*.

**Americas.** In the drier areas of tropical North and Central America spineless cacti (*Opuntia* spp.) and mesquite (*Prosopis juliflora*) are important browse plants. Very large areas in tropical South America are dominated by shrubs. These include the *cerrado* and *caatinga* of central, eastern and northeastern Brazil, the coastal deserts of Peru and northern Chile, the *chaco* in Paraguay, and in a montane tropical climate the *puna* of the high Andes. Important browse plants in tropical South America include *Acacia* spp., *Atriplex* spp., *Capparis* spp., *Cercidium* spp., *Chenopodium paniculatum*, *Lycium* spp., *Maytenus* spp., *Opuntia* spp. and *Prosopis* spp.

**Asia.** Browse plants are of major importance to semi-subsistence livestock owners, particularly in the drier areas of tropical south Asia and many different species are utilised.

**Oceania.** Everist (1972) stated that some 200 Australian woody plants are grazed by livestock, but not all these species will thrive in the drier tropical areas. Browse plants of major importance are species of *Acacia*, *Atriplex* and *Kochia*.

Some details of a limited selection of particularly useful tropical browse plants are provided in Table 5. Two browse species, *Acacia albida* and *A. senegal* are of particular importance in Africa and additional information is provided on the utilisation of these species.

*Acacia albida* is a rather unique leguminous forage tree, indigenous throughout the drier regions of tropical Africa and also found in Western Asia. It is unique because it retains leaves throughout the dry season, shedding them as the rains begin. Thus green forage is available throughout the dry season and the seed pods ripen at the end of the dry season, when livestock feed is scarce. In addition the tree provides good shade during the hot dry months, whilst crops can be grown beneath it during the wet months as at that time the branches are bare.

If there is no groundwater this tree grows in areas where annual rainfall is approximately 650 mm, but if groundwater is available it can survive in areas with 300 mm rainfall, on account of its deep roots. One disadvantage is that it grows very slowly during the first 15–20 years and if crops are grown beneath it during the wet season a further disadvantage is that it provides an habitat for weaver birds, a major pest of cereal crops.

When the tree is mature branches can be lopped to provide dry season browse and pod production is of the order of 150 kg per annum per tree. Ground forage species grow particularly well under this tree during the wet season as there is no shading effect. It is claimed (National Research Council, 1979) that in Niger stocking rates under *Acacia albida* may be double those achieved elsewhere in the same environment.

Many observers believe that the stand of *Acacia albida* is declining throughout the drier regions of Africa. This may be due to overgrazing, slow growing seedlings being continuously destroyed and dead trees not replaced. There is, therefore, some demand for the replanting of this tree on a large scale in the pastoral areas.

Another leguminous forage tree of particular value in the Sahel climatic zone in tropical Africa is the gum Arabic tree (*Acacia senegal*). It will grow in areas with an annual rainfall of 300 mm. In the past it was customary in regions such as the western savanna of the Sudan to rotate crops such as bulrush millet (*Pennisetum typhoideum*) with a bush fallow that included *A. senegal*. When an area was cleared for cropping the *A. senegal* trees were cut down near to their base but were not destroyed, being allowed to regenerate during the cropping period. Due to an increase in human population, with increasing scarcity of land, the bush fallow period has shortened, so that regenerating *A. senegal* trees no longer mature and are gradually disappearing. At the same time, on account of overstocking, few *A. senegal* trees mature from seed. As gum arabic is an important crop and *A. senegal* is a useful leguminous forage tree the loss in overall productivity is considerable.

It has been suggested in several countries in which *A. senegal* is indigenous that this tree could be incorporated into a cattle/tree crop/ground crop system, though it is not known whether investigation of such a system is now taking place. One proposed 20-year rotational system is shown diagrammatically in Fig. 6. After clearing the bush, millet and/or other crops would be grown for five years. During the final cropping year *A. senegal* seedlings

would be planted in the cropped area with a grass/legume seed mixture undersown. For the next six years the forage growing between the young *A. senegal* trees would be cut and fed to cattle kept elsewhere. During the eleventh year the first crop of gum arabic would be obtained from the *A. senegal* trees and gum arabic cropping would continue until the twentieth year when all the trees would be cut for firewood and the rotation recommenced. From the eleventh to the twentieth year grazing would be controlled and there would be some controlled lopping of the *A. senegal* to provide browse at appropriate seasons. *A. senegal* pods would also be available as a feed for cattle. It is estimated that in this system for a period of 10–11 years gum arabic would be produced at the rate of 50 kg per annum per ha, firewood would be produced at the rate of 10 m<sup>3</sup> per ha once in 20 years and that the millet crop would benefit from the increase in fertility that should take place during the 15 year tree crop/forage period. It is difficult to assess what effect this system would have on cattle production. At present the overall stocking rate on range in the ecosystem is one l.s.u. per 10–15 ha. However, if cut forage is available for five years of the rotation and some economic method of forage conservation can be introduced, it should be possible to radically improve the milk production of indigenous cattle and slightly improve the stocking rates.

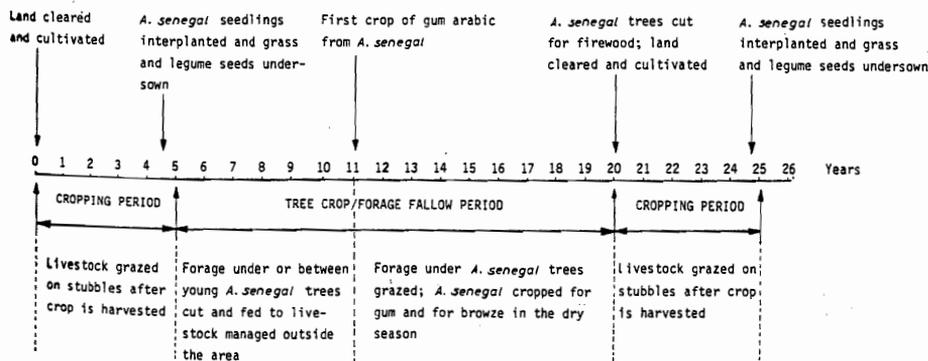


Fig. 6. Diagrammatic representation of a 20-year-old *Acacia senegal* /crop/forage/livestock rotational system.

If pressure on land resources increases, as is likely, and a 5-year cropping period in 20 years is insufficient, the rotation could be reduced to 15 years by planting the *A. senegal* seedlings during the first year of the cropping period. If it becomes necessary to crop continuously, the *A. senegal* could be used as a hedgerow plant or windbreak between crop fields.

#### REFERENCES

- Apolo, W., 1979. Control de la escorrentía y erosión mediante sistemas silvopastoriles. CATIE, Turrialba.

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- Avila, M., Ruiz, M., Pezo, D. and Buiz, A., 1979. The importance of the forestry component on small cattle farms of Costa Rica. CATIE, Turrialba.
- Barker, R. and Nyberg, A.J., 1968. Coconut/cattle enterprises in the Philippines. *Philipp. Agric.*, 52: 49-60.
- Beale, I.F., 1973. Tree density effects on yields of herbage and tree components in South West Qld. mulga (*Acacia aneura* F. Huell) scrub. *Trop. Grassl.*, 7: 135-142.
- Bene, J., Beall, H.W. and Cole, A., 1977. Trees, food and people; land management in the tropics. IDRC, Ottawa.
- Bille, J.C., 1977. Etude de la production primaire nette d'un ecosysteme Sahlien. *Trav. Doc. ORSTOM*, No. 65.
- Bishop, J.P., 1979. Livestock-forestry production in the Spanish American humid tropics. *Proc. Workshop Agro-Forestry Systems in Latin America*, March 1979, CATIE, Turrialba.
- Blancou, J., Calvet, H., Friot, D. and Valenza, J., 1977. Composition du pasturage naturel consommé par les bovins en milieu tropical. Colloque sur les recherches sur l'élevage bovin en zone tropical humide. Bouaké, Côte d'Ivoire.
- Budowski, G., 1980. The place of agro-forestry in managing tropical forests. *Int. Symp. Trop. For. Util. Cons.*, Yale Univ. New Haven, 15-16 April. CATIE, Turrialba.
- Child, R., 1974. *Coconuts*. Longman, London, 2nd edn.
- Coconut Industry Board, Jamaica, 1970-71. 11th Rep. Res. Dept., pp. 47-48.
- Combe, J., 1979. *Alnus acuminata* with grazing and mowing pasture: Las Nubes de Coronado, Costa Rica. *Proc. Workshop Agro-Forestry Systems in Latin America*, March 1979, CATIE, Turrialba, pp. 199-201.
- Deccarett, M. and Blydenstein, J., 1968. Le influencia de árboles leguminosos y no leguminosos sobre el forraje que crece bajo ellos. *Turrialba (Costa Rica)*, 18(4): 405-408.
- De Silva, M.A.T., 1961. Cover crops under coconuts. *Ceylon Coconut Planters Rev.*, 11: 17.
- Donohoe, T., 1980. Cattle and timber are profitable, compatible, practical. *Florida Cattleman*, 49(10): 94-95.
- Eriksen, F. and Whitney, A.S., 1977. Performance of tropical forage grasses and legumes under different light intensities. *Reg. Semn. Pasture Res. Dev. Solomon Isl. and Pacific Region Proc.* Honiara, Solomon Islands, 29 August-6 September 1977, pp. 180-190.
- Everist, S.L., 1972. Australia. In: *Wildland Shrubs - Their Biology and Utilisation*. USDA For. Serv. Gen. Tech. Rep., INT-1.
- Fats and Oil Team, FAO, 1979. The world coconut situation and outlook. 5th Session, FAO Tech. Working Party on Coconut Production, Protection and Processing. Manila, Philippines, 3-8 December 1979. FAO, Rome.
- Ferdinandez, D.E.F., 1970. Report of the agrostologist - 1964 - Ceylon. *Coconut Quart.*, 21: 49.
- Ferdinandez, D.E.F., 1973. Utilisation of coconut lands for pasture development. *Ceylon Coconut Plant Rev.*, 7: 14-19.
- Gregor, E.W., 1973. Integration of grazing in tropical forestry. *Mexico y sus Bosques*, 12(5): 27-33.
- Hartley, C.W.S., 1977. *The Oil Palm*. Longman, London.
- Hill, G.D., 1969. Grazing under coconuts in the Morobe District. *Papua N.G. Agric. J.*, 21: 10-12.
- King, K.F.S., 1979. Agroforestry. *Proc. 50th Tropische Landbouwdag*, 1978. Dept. Agric. Res. Royal Tropical Inst., Amsterdam, Bull. 303.
- Leather, R.I., 1972. Coconut research in Fiji. *Fiji Agric. J.*, 34: 3-9.
- Le Houérou, H.N., 1978. The role of shrubs and trees in the management of natural grazing lands (with particular reference to protein production). 8th World For. Cong. Jakarta, 16-18 October 1978.

- Loján, L., 1979. Agroforestry in Southern Ecuador. Proc. Workshop Agro-forestry Systems in Latin America. Turrialba, Costa Rica, March 1979, CATIE, Turrialba, pp. 127-129.
- Lowe, J.S., 1968. Sheep under rubber. Rubber Res. Inst., Western Malaysia, Planters Bull., 98: 141.
- Lowe, J.S., 1969. The integration of livestock with rubber. Planter (Malaysia), 45: 18-21.
- Ludlow, M.M., Wilson, G.L. and Heslehurst, M.R., 1974. Studies on the productivity of tropical pasture plants. V. Effect of shading on growth, photosynthesis and respiration in two grasses and two legumes. Aust. J. Agric. Res., 25: 425-433.
- National Research Council, 1979. Tropical Legumes. Resources for the Future. National Academy of Sciences, Washington, D.C.
- Obisara, 1970. Livestock on estates. Planter (Malaysia), 46: 410.
- Ohler, J.G., 1969. Cattle under coconuts. Trop. Abstr., 24: 639-645.
- Payne, W.J.A., 1976. Systems of beef production in developing countries. In: A.J. Smith (Editor), Beef Cattle Production in Developing Countries. CTVM, Edinburgh.
- Payne, W.J.A. and Rollinson, D.H.L., 1976. Madura cattle. Z. Tierz. Zuechtungsbiol., 93: 89-100.
- Plucknett, D.L., 1972. Management of natural and established pastures for cattle production under coconuts. Proc. Reg. Semn. on Pasture and Cattle under Coconuts. South Pacific Commission, Noumea, p. 109.
- Prentice, W.E., 1979. Rehabilitation of exhausted lands in the upper Ecuadorian Amazon. Proc. Workshop Agro-Forestry Systems in Latin America, March 1979, CATIE, Turrialba, pp. 153-157.
- Queen, A.H. and Foale, M.A., 1961. The improvement of the coconut palm production of the high islands of the tropical Pacific. Symp. Tropical Crops Improvement, 10th Pacific Sci. Cong. South Pacific Commission, Noumea, pp. 65-69.
- Ranacou, E., 1972. Pasture species under coconuts. Proc. Reg. Semn. on Pastures and Cattle under Coconuts, South Pacific Commission, Noumea, p. 95.
- Reategui, R.R., 1979. Development of integrated agricultural livestock and forestry production systems in tropical Peru. Proc. Workshop Agro-Forestry Systems in Latin America. March 1979, CATIE, Turrialba, pp. 91-100.
- Reynolds, S.G., 1977. Pasture research and development in Western Samoa. Reg. Semn. Past. Res. Devl. Solomon Isl. and Pacific Region Honiara, Solomon Is., 29 August-6 September 1977, pp. 86-100.
- Rombaut, D., 1974. Etude sur l'élevage bovin dans les palmeraies de Cote d'Ivoire. Oleagineux, 29: 121.
- Rosero, P. and Gewald, N., 1979. Growth of laurel (*Cordia alliodora*) in coffee and cocoa plantations and pastures in the Atlantic region of Costa Rica. Proc. Workshop Agro-Forestry Systems in Latin America, March 1979, CATIE, Turrialba, pp. 205-208.
- Sajise, P.E., 1973. Competition within the pasture-coconut plant community. ASPAC Training Course on Pasture Production under the Coconut Palms. Davao City, Philippines, Oct. 1973.
- Salgado, M.L.N., 1951. Preliminary studies in the chemistry of cattle manuring on coconut estates. Trop. Agric. (Ceylon), 107: 218-224.
- Santhirasegarum, K., 1964. The effect of pasture on the yield of coconuts. Ceylon Ass. Advance Sci., Section B, 20th Ann. Sess., 22-25 September 1974.
- Santhirasegarum, K., 1966. The effects of pasture on the yield of coconuts. J. Agric. Soc. Trinidad Tobago, 66: 183-193.
- Singh, A. and Naidu, R.S., 1973. Coconut nutritional survey. Res. Div. Dept. Agric., Suva, Fiji.
- Steel, R.J.H. and Humphreys, L.R., 1974. Growth and phosphorus response of some pasture legumes sown under coconuts in Bali. Trop. Grassl., 8: 171-178.

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- Thomas, D., 1978. Pastures and livestock under tree crops in the humid tropics. *Trop. Agric. (Trinidad)*, 55(1): 39-44.
- Wangsudijaja, S.S., 1980. A silvo-pastoral system for the revegetation of private lands. Seminar Forest Faculty, Gadjah Mada University, Indonesia.
- Watson, S.E., 1977. Results of the grazing trial coconuts at Longatu, Russell Islands. *Reg. Semn. Past. Res. Dev. Solomon Isl. and Pacific Region Proc.*, Honiara, Solomon Islands, 29 August-6 September, 1977, pp. 113-124.
- Whiteman, P.C., 1977. Pastures in plantation agriculture. *Reg. Semn. Past. Res. Dev. Solomon Isl. and Pacific Region Proc.*, Honiara, Solomon Islands, 29 August-6 September, 1977, pp. 144-153.
- Whiteman, P.C., Bohoquez, M. and Ranacou, E.N., 1974. Shading tolerance in four tropical pasture legume species. *Proc. 12th Int. Grassl. Cong., Moscow*, pp. 402-407.