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Role of Woody Perennials in Animal Agroforestry

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Corrigenda

Agroforestry Systems 1:131-163

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Page no.	line(s)	should read, in the relevant places, as shown below
131	4-5	... , or industrial material, woody products and food ...
131	26-27	... La baja productividad y palatabilidad relativa de forrage con alto contenido proteico ...
135	22-23	...ranging from 3.243 (*Acacia cyclops*) to 0.136 (*Periploca loevigata*): ...
141	Table 3 (continued) asterisked line	...Digestible Crude Protein (DCP) ...
142	31-32	... liveweight gain ha^{-1} year^{-1} was 19.4 and 12.9 kg for cattle and 20.1 and 13.4 kg for sheep ...
143	7-8	... intake of 3.2 and 3.1 percent of body weight ...
143	10-11	..., the slow rates would suggest a mineral deficiency or illness ...
144	13	(beef strategy or BS): ...
145	8	... chipboard manufacturing ...
145	9	... economic analysis carried out by Gisz and Sar (1980) challenges the results ...
151	3-4	... under the canopies of leguminous trees in Rajhastan, Shankar, Dadhich and Saxena(1976) found ...
155	16-17	... much simpler than for foilage, although labour-intensive, if there is a need to use it ...
157	45-46	Gisz, P. and Sar, N.L.(1980) Economic evaluation of an agroforestry project. Misc. Bull. 33. Dept. of Agric. N.S.W., Australia.

Agroforestry Systems 1:131–163.

Role of woody perennials in animal agroforestry

FILEMON TORRES

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Abstract: Two main roles are identified in the review: the productive one, where woody perennials yield a material output (fuel, fodder, etc.), and the 'service' type, with no tangible product (shelter, nutrient recycling, etc.). In their productive role trees and shrubs may supply fodder in browsing systems, or industrial material, wood products and food in forest and plantation grazing systems. Service roles, rarely divorced from productive ones, arise mainly from relationships between woody perennials and the herbaceous vegetation growing in their vicinity. As a fodder source, the relatively low productivity and palatability of high protein content foliage from most woody perennials would indicate a supplementary role, particularly during dry seasons in arid and semiarid zones. In these type of lands pod-bearing trees seem to have a greater potential for improving fodder production in silvopastoral systems. The negative effect of trees on pasture production in forest and plantation grazing is compensated by their contribution to the system through other products. Available data would support the potential of certain species of woody perennials to foster pasture growing underneath, mainly through soil enrichment. Windbreaks can also indirectly benefit pasture growth, by decreasing water loss from the soil. It is postulated that research efforts in animal agroforestry should be focused on woody perennials for browsing systems, particularly on pod-bearing trees having beneficial effects on the herbaceous layer growing underneath.

Resumen: Papel de leñosas perennes en sistemas agrosilvopastoriles – La revision identifica dos principales papeles: el productivo, donde las leñosas perennes rinden un producto material (leña, forraje, etc.), y el de 'servicio', sin produccion tangible (sombra, reciclaje de nutrientes, etc.). En su papel productivo arboles y arbustos pueden suplir forraje en sistemas de ramoneo, o madera, material para industria y alimento en los sistemas de pastoreo en el bosque o en plantaciones. El papel de servicio, raramente separado del productivo, surje principalmente de las relaciones entre las leñosas perennes y la vegetacion herbacea que crece en su proximidad. La baja productividad y palatabidad relativa de forraje con alto contenido proteico indicaria que, como fuente de forraje, el principal papel de las leñosas perennes es de tipo suplementario, particularmente durante la estacion seca en zonas aridas y semi-aridas. En el pastoreo en bosques y plantaciones el efecto negativo de los arboles sobre la produccion de pasto es compensado por la contribucion de los mismos al sistema a traves de otros productos. La informacion disponible apoyaria el potencial de ciertas especies leñosas para fomentar el desarrollo de pasturas que crecen bajo las mismos, principalmente a traves del enriquecimiento de los suelos. Rompevientos pueden tambien beneficiar indirectamente a las pasturas al disminuir las perdidas de agua del suelo. Se postula que los esfuerzos de investigacion en sistemas agrosilvopastoriles deben concentrarse en leñosas perennes para sistemas de ramoneo, particularmente en arboles que produzcan vainas y que tengan efectos favorables sobre el estrato herbaceo que crece debajo de ellos.

Résumé: Le rôle des plantes ligneuses dans l'agroforesterie animale – Deux rôles majeurs sont identifiés dans la revue: celui de production, où les plantes ligneuses rendent un produit matériel (bois de chauffage, fourrage etc.) et celui de 'service' qui n'a pas de rendement matériel (abri, recyclage de minéraux, etc.). Par leur rôle productif, les arbres et arbustes peuvent produire du fourrage dans les systèmes de pâture, ou des matériaux industriels, des produits ligneux et de la nourriture dans les systèmes de pâturage en forêt ou en plantation. Les rôles de service, rarement séparables de ceux de production, proviennent surtout des rapports entre les plantes ligneuses et la végétation herbacée qui croît à leur proximité. Comme source de fourrage, la productivité et la palatabilité relativement basse du feuillage à haute teneur en protéine qui caractérise la plupart des plantes ligneuses semble indiquer un rôle supplémentaire, particulièrement durant la saison sèche dans les zones arides et semi-arides. Dans ces régions, les arbres qui produisent des gousses semblent avoir un meilleur potentiel pour améliorer la production de fourrage dans les systèmes silvopastoraux.

L'influence néfaste des arbres sur la production herbagère dans les situations de pâturages en forêt ou en plantation, est compensée par leur contribution au système par d'autres produits. Les données disponibles semblent supporter l'idée voulant que certaines plantes ligneuses ont le potentiel d'encourager la croissance de pâture sous-jacente, principalement par l'intermédiaire d'un enrichissement du sol. Les brises-vent peuvent aussi être avantageux pour le rendement du pâturage en réduisant les pertes d'eau du sol. Il est postulé que les efforts de recherche en agroforesterie animale devraient se concentrer sur les plantes ligneuses pour les systèmes de pâture arborée qui ont une influence avantageuse sur la strate herbacée sous-jacente.

1. Introduction

Many definitions of agroforestry have been proposed (see Agroforestry Systems, 1982, Vol. 1, No. 1: 7–12) and its discussion is beyond the scope of this paper. Nevertheless, there appears to be consensus on that such systems involve the combination of woody perennials with herbaceous crops, including pastures, with or without animals. In this context, animal agroforestry is proposed as a generic name for all agroforestry systems which include animals (for production or performance) as one of their components. It has been suggested that these systems can be called silvopastoral when they include trees or shrubs, pasture and animals, while the agrosilvopastoral ones would contain herbaceous food crops in addition to those components included in silvopastoral systems (Torres, 1982).

Within these systems woody perennials can play a productive or a service role. The former could be characterized as that producing a material output (e.g., timber, fuel, fruits, fodder), while the service one would not yield a tangible product (e.g., shelter, nutrient recycling). Most of the times the role of woody components in land management systems will not be limited to either a productive or service one, but will probably play both. Notwithstanding this, such division appears as a functional way of approaching the discussion on the subject.

2. The productive role

2.1 Browsing systems

Browse has been defined as the 'shoots or sprouts, specially tender twigs and stems of woody plants with their leaves, which are cropped to a varying extent by domestic and wild animals' (Dayton, 1931, cited by Skerman, 1971). However, in this case the term will be broadened to include fruit or pods, which can be more valuable than foliage, particularly if the woody component happens to be a deciduous one.

A general paper highlighting the role of browse plants as drought reserves and their feeding value as source of protein-rich fodder is the one by Gray

(1970). The use of fodder trees mainly as drought reserves has been emphasized by Moore (1972). A comprehensive discussion on the role of browse in the management of natural grazing lands, including the importance of fodder 'trubs' (trees and shrubs) in different ecological zones and the potential of some components (*Opuntia* sp., *Atriplex* sp., *Acacia* sp., etc.) has been presented by Le Houérou (1980), who postulates that technologies based on permanent feed supply from fodder trubs can transform pastoral production systems into settled agropastoral ones. An extensive review by Ibrahim (1981) presents one of the most comprehensive listing of references (175) on factors affecting dry matter yield, palatability, nutritive value and utilization of fodder trubs, including recommendations for further research and development on fodder trees and shrubs. The role of woody components in animal production has also been discussed by Felker (1980), McKell and Malechek (1980). Given the different aspects involved in discussing the role of woody components in browsing systems, references are arranged according to their contribution to the knowledge on species, biomass productivity and nutritive value. Relationships between woody and herbaceous conponents will be dealt with later on, under the topic of the 'service' role of trees and shrubs.

2.1.1 Trub species. Probably as a reflection of their importance in rangeland management, African fodder trubs have been described in several papers. For the Sahelian zone the thesis by Touzeau (1973) describes 42 species belonging to 15 families. Description not only includes botanical and ecological characteristics but also distribution and utilization. Kadambi (1963) has made a selection of 10 fodder trees for the different ecological zones of Ghana, based upon their agronomic and forage characteristics. Predominant browse plants in the East African highlands are described by Dougall and Bogdan (1957) with emphasis in their use, including chemical composition. A list of the main browse plants in the Sudanian zone of West Africa is given by Toutain (1980).

For the southern part of Africa Jurriaanse (1973) thoroughly describes 6 species useful to humid and arid areas, but concludes that they have not reached a development stage which makes them worth propagating for economic fodder production. For the more arid areas (100–500 mm rainfall), however, Kock (1967) believes that *Opuntia* sp. and *Atriplex nummularia* can play an important role in limiting fodder shortages during droughts.

A pioneer work on fodder trees and shrubs of Australia is the one by Everist (1969), including more than 100 species. Seventeen important fodder trub species for the arid grazing country in western New South Wales are described by Stannard and Condon (1968), who visualize their contribution essentially as drought reserves and to prevent soil wind erosion. Carob, Mesquite and Honey locust were proposed by Eardley (1945) for south Australia. The agronomic characteristics and uses of the widely distributed genus Leucaena is described by Brewbaker (1976). A less known but promising drought resistant legume shrub, *Stylosanthes scabra* Cv. *Seca*, has been registered in the J. Austr. Inst. of Agric. Sci. (1978).

From the Americas the most relevant genus seems *Prosopis* sp., which potential has been reviewed by Felker (1979), who concluded that pod yield could go up to 10 000 kg ha^{-1} ahd that selections can be developed for various ecological niches and uses.

In spite of the widespread use of fodder trubs in the Indian subcontinent, it does not seem to be a profuse literature describing useful species. Sharma (1977) briefly characterises more than 30 winter and summer fodder trees of Himachal Pradesh according to their palatability. A thesis by Panday (1975) presents a systematic list of fodder trubs in the Sindhupalchok District of Nepal, as well as observations and comments on the occurrences and propagation, production and utilization practices. After concluding that trub leaves make up the bulk of the green fodder available during the dry season, he proposes a selection criteria on the basis of chemical composition and farmers observations. Mann (1980) has described the salient features of *Prosopis cineraria*, the 'wonder' tree of the arid N.W. India, used by the local population as a source of fuelwood, fodder and to improve soil fertility.

A comprehensive list of leguminous browse species for the tropics can be found in the book by Skerman (1977), and complemented with the paper by Felker and Bandurski (1979).

2.1.2. Trub productivity. Should the more ample definition of browse be accepted, i.e., including pod utilization, it would be convenient to deal separately with leaf-twig and pod production. The difficulty involved in estimating 'useful' production of leaf-twig (that accessible to the browsing animal) and the 'substitution' approach (of woody by herbaceous components) that has prevailed in range improvement, may have precluded research on trub dry matter production. A valuable review on production of browse in the savanna regions is that by Trollope (1981). Using data from other authors, he mentions that mean total biomass of such savannas is approximately 20 000 kg ha^{-1} yr^{-1}, of which 1500 are twigs and leaves, 600 stems and branches and 1000 come from growth of the herbaceous layers. Applying existing data the same author estimates that only 33 to 76% of those browsable leaves and twigs would be within reach of the animals, or 500 to 1150 kg ha^{-1} yr^{-1}. As a result of this and other available information, Trollope (1981) concludes that '. . . . data emphasises an important principle in savanna ecology, viz. that the herbaceous grass layer is potentially able to produce more edible plant material for domestic livestock than the browse layer. However, the grass sward can be extremely variable in its production, mainly in response to seasonal fluctuations in rainfall. Conversely, it would appear that the production of browse by the woody component is much less variable and less influenced by short-term fluctuations in rainfall, presumably because the woody plants possess deeper root systems'.

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Another interesting paper on primary production of fodder trubs in the African tropics is that by Bille (1980), who shows a relationship between stem circumference and foliage and fruit biomass for several browse species in the Sudano-Sahelian zone, within a rainfall range of 250 to 600 mm. The relationship, of the form log biomass = a x log diameter + c, has a mean value of 2 for *a* and 1 for *c*. It means that for trub stem diameters of 5, 10 and 15 cm, biomass production will be 0.250, 2.2 and 6.2 kg respectively. An average tree in the Sahel would then produce a kilogram of leaves plus 0.250 of fruits and 4–5 kg of branches; or about 1000 kg ha^{-1} of foliage. This productivity is affected by the browsing regime. Cisse (1980), experimenting with trubs from the same Sudano-Sahelian zone, found out that frequency and intensity of stripping would affect yield by as much as 100%, depending on species.

For the Sahel, Penning de Vries and Djiteye (1982) have estimated that the mean annual production of leaves of woody species ranges from around 50 kg ha^{-1} for the 500 mm rainfall zone (where soil cover of these species was in the order of 5%) to 1000 kg ha^{-1} in the 1000 mm zone (with a soil cover of 100%).

In the Mediterranean zone Le Houerou et al. (1982) has also found a relationship between biomass and canopy diameter using data from 622 shrubs of 4 species. The average production of leaves/phyllods per shrub for 16 species was 1.365 kg ranging from 3.243 (*Acacia cyclops*) to 136 (*Periploca loevigata*); *Atriplex* sp. faliing within the average. This value does not differ substantially from that measured by Jones, Hodgkinson and Rixon (1969) for *Atriplex nummularia* at 500 days from germination: 2.330 kg.

Studies on the productivity of around 20 shrub/brush species in the native grasslands of North America indicate that annual production ranges from 20 to 600 g/plant, and is affected by intensity and frequency of defoliation (Willard and McKell, 1978; Lay, 1965; and Garrison, 1953).

The marked interest in *Leucaena* sp. has led to several experiments on its productivity (Brewbaker, Plucknett and Gonzales, 1972; Hill, 1971; Alferez, 1977; Ferraris, 1979). In humid Hawaii, Guevara, Whitney, and Thompson (1978) studied the productivity of shrubby and arboreal types of *Leucaena leucocephala* under different plant populations and height of cuttings. A population density of 133.000 plants (15 x 50 cm) and a cutting height of 105 cm produced higher forage yields with both types, being higher for the shrubby type (12.9 t ha^{-1} yr^{-1}) than the arboreal type (11.5 t ha^{-1} yr^{-1}), or 95 and 85 g/plant respectively. At Los Baños, Philippines, Mendoza, Altamirano and Javier (1976) experimented with frequency and intensity of cutting on a cv. Peru planted at 3.0 x 0.05 m (66 000 pl ha^{-1}). Cutting height significantly affected total dry matter yield, which was 10.7, 15.8 and 23.6 t ha^{-1} for 0.15, 1.5 and 3.0 m respectively, which correspond to 162, 239 and 358 g/plant/year. Under the sub-humid conditions of Queensland, Australia, Hutton and Beattie (1976) report a total production of 5 tons ha^{-1} (only

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1.9 t of edible DM) for a fertilized Peruvian type at a density of 10 000 plant ha^{-1} cut a 15 cm high 3 times a year, or 500 g/plant. In the semi-arid region of India (Jhansi), Pathak, Rai and Deb Roy (1980) studied the effect of population density and frequency and intensity of cutting. On a 3 year average, density was the most important factor affecting total yield, which ranged from 5.4 t ha^{-1} for 4 plants/m^2 to 1.9 t for 1.5 pl/m^2 (135 and 127 g/plant/year respectively).

For an *Acacia aneura* community in Queensland, Beale (1973) reports that foliage weight per tree varied from 3 to 5 kg depending on density (640 to 40 trees ha^{-1}), leading to a production of 1900 to 200 kg ha^{-1} respectively.

The literature reviewed appears to be consistent in showing a relatively small scope for trubs as components that can substantially increase production of edible foliage matter, particularly in the arid and semi-arid zones.

Information available on pod production is even scarcer. Data compiled by Felker and Bandurski (1979) would indicate that species such as *Prosopis* sp., *Gleditsia triacanthos* and *Acacia albida* could produce in the order of 3–10 t ha^{-1} in different ecological zones. In the case of *Prosopis tamarugo* in the arid north of Chile production per tree ranges from 20 to 70 kg for 14 to 22 year old plants at a density of 100 trees ha^{-1} (Elgueta S. and Calderon S., 1971).

2.1.3 Trub nutritive value. The nutritive value of any particular fodder depends not only on its nutrient content but on the amount consumed and assimilated by the animal. Although there is a considerable wealth of information on chemical composition of fodder trubs, few of them have been evaluated in terms of animal response. A review on browse in nutrition of grazing animal was carried out by Wilson (1969), who concluded then that fodder trubs have not been shown to make a major contribution to the nutrition of domestic or most game animals and that further studies of browse-grass comparisons were needed.

The role of browsing appears to be particularly relevant for animal production systems based upon the utilization of rangelands in arid and semi-arid zones. Under these conditions protein content in the diet has been shown to be the most limiting factor affecting liveweight gains. This was the conclusion of a thorough analysis carried out by Pratchett et al. (1977) relating six range parameters, measured monthly over an 11-month period on nine ranches distributed throughout the main ecological zones of Botswana, to the monthly liveweight changes of growing cattle. Linear, quadratic and multiple regressions all indicated that liveweight change was influenced primarily by the crude protein content of the herbage selected, which accounted for 54% of the variation, while digestibility of the same samples accounted for 32%. They concluded that research efforts must be directed towards increasing the crude protein content of the diet available to beef cattle. In a study carried out with steers in the mixed tree savanna of the Transvaal, South Africa,

Table 1. Crude protein content of trub leaves and twigs

Species	Region	CP (%)	References
Zizyphus mistol	Argentina	25.9	Diaz, 1962
Acacia aneura	Queensland, Austr.	13.1	Harvey, 1952
Grewia sp.	Kenya	19.76	Wilson, 1963
Baphia bequaertii	Zambia	22.38	Lawton, 1975
Julbernardia paniculata	Zambia	12.38	Lawton, 1975
Bauhinia variegata	India	15.6	Lawton, 1975
Gleditsia triacanthos	Pakistan	11.8	Khan, 1975
Zizyphus mauritania	Pakistan	11.3	Khan, 1975
Acacia arabica	Pakistan	12.8	Khan, 1975
Albizzia lebbeck	Pakistan	22.0	Malik, Sheik & Shah, 1967
Acacia arabica	Pakistan	20.0	Malik, Sheik & Shah, 1967
Bauhinia variegata	Pakistan	18.5	Malik, Sheik & Shah, 1967
Azadirachta indica	Pakistan	13.4	Malik, Sheik & Shah, 1967
Ficus religiosa	Pakistan	10.8	Malik, Sheik & Shah, 1967
Gliricidia sepium	Virgin Islands	17.4	Oakes & Skow, 1962
Leucaena leucocephala	Virgin Islands	16.0	Oakes & Skow, 1962
Albizzia lebbeck (whole)	Virgin Islands	16.2	Oakes & Skow, 1962
Prosopis spicigera	India	15.4	Gupta & Mathur, 1974
Commiphora africana	Sahel	14.2	Clanet & Gillet, 1980
Alchornea cordifolia	Nigeria	23.0	Mecha & Agdebola, 1980
Baphia pubescens	Nigeria	24.3	Mecha & Agdebola, 1980
Cajanus cajan	Nigeria	29.8	Mecha & Agdebola, 1980
Combretum nigricans	Sahel	13.2	Bartha, 1970
Gueira senegalensis	Sahel	13.9	Bartha, 1970
Grifforia simplicifolia	Ghana	15.7	Rose Innes & Maybe, 1964

Zimmerman (1980) estimated that the intake of digestible crude protein accounted for 79% of the variation in daily liveweight change of the cattle. A less conclusive but still supportive evidence comes from the work by McKay and Frandsen (1969) in the semi-arid upland areas of Kenya, and that of Ward (1975) for the rangelands in Arizona, particularly during summer periods. This may originate in the known negative relationship between temperature and crude protein content in grasses (Deinum, 1966), as well as the direct one between crude protein content in the diet and fiber digestibility.

An increase in the availability of crude protein to the grazing/browsing ruminant could be achieved through the introduction of fodder trubs, which are known for their high protein content. This possibility is somewhat substantiated by Rees (1973), who assessed the potential of bush utilization by cattle during the latter half of the dry season in a marginal area of Zambia. Although the high standard error of the estimate precludes any firm conclusions, it appears that the fodder selected by 4 fistulated steers from 10 trubs contained 12 to 17% protein, while that of the grass was only 3%. Göhl (1981) has compiled literature on trub composition. A compilation of some of the available information on chemical composition of trub leaves and pods would indicate their potential as a protein supplement to the fodder available in the tropical and sub-tropical rangelands (see Tables 1 and 2). An analysis of a similar work done by Le Houerou (1980) on browse species of West Africa

Table 2. Crude protein content of trub pods and seeds

Species	Region	Pods	Seeds	References
Acacia aroma	Argentina	14.0		Diaz, 1962
Acacia cavenia	Argentina	11.1		Diaz, 1962
Cesalpinia paraguariensis	Argentina	4.6		Diaz, 1962
Geoffrea decorticans	Argentina	6.4		Diaz, 1962
Prosopis alba	Argentina	8.9		Diaz, 1962
Prosopis nigra	Argentina	8.2		Diaz, 1962
Zizyphus mistol	Argentina	5.4		Diaz, 1962
Acacia albida	Tanzania	13.5	26.6	Gwynne, 1969
Acacia albida	Uganda	10.0	28.4	Gwynne, 1969
Acacia nilotica	Kenya	12.4	20.8	Gwynne, 1969
Acacia sieberiana	Uganda	11.7	18.9	Gwynne, 1969
Prosopis juliflora	India	10.1		Mahadevan, 1954
Ceratonia siliqua	Brasil(s)	7.5	13.1	Hall, G., 1976
Phitecolobium saman	Venezuela	14.6		Fornaroli, 1961
Acacia albida	Zambia	11.5	22.2	Skerman, 1977
Acacia litakuensis	Rhodesia	17.3	37.8	Skerman, 1977
Acacia nilotica	Uganda	10.0		Skerman, 1977
Acacia nubica	Kenya	15.2		Skerman, 1977
Acacia polyacantha	Zambia	10.4	27.4	Skerman, 1977
Acacia senegal	Uganda	19.6		Skerman, 1977
Acacia sieberiana	Zambia	10.3	18.5	Skerman, 1977
Acacia tortilis	Kenya	14.1		Skerman, 1977
Albizia versicolor	Zambia	12.6		Skerman, 1977
Bauhinia carronii	Australia	10.8		Everist, 1969
Ceratonia siliqua	Australia	9.3		Everist, 1969
Dichrostachys cinerea	Rhodesia	11.4		Everist, 1969
Gleditsia triacanthos	Australia	14.3		Everist, 1969
Piliostigma thonningii	Rhodesia	6.4		Everist, 1969
Acacia nilotica	Siwalik	16.1		Lal, M., 1977
Acacia cynophylla	Cyprus		30.7	Ramadan, 1957
Dalbergia sisso	Agra	11.9		Saraswat, Singh and Sachdeva, 1974

shows that the average protein content of 55 non-legume species is 14.1%, while that of 36 legume ones is 18.8%. Carew, Mba and Egbunike (1981) found that in the humid zone of Nigeria the mean crude protein contents of browse, i.e., trees, shrubs and herbs (18.3, 19.7 and 19.4 respectively) were higher than those for grasses (11.1%).

This potential becomes particularly evident when protein content of browse species is compared with that of grasses from the same piece of land and harvested at the same time. Such comparison was reported by Rose Innes (1965) for monthly recordings between May and December in the coastal and interior savanna of Ghana, including data from 4 browse species and unidentified native grass. The average protein content of 8 observations in the coastal savanna was 18.1 and 5.8% for browse and grasses respectively. Corresponding values for the interior savanna were 15.1 and 4.8%. Moreover, it should be mentioned that grass protein content was always lower than 50% of that in browse (and as low as 8%), with the exception of that for the coastal savanna in May, when it reached 61% of the browse content.

As expected, protein contents will change with season (Momin and Ray, 1943, Rose Innes and Mabey, 1964b, and McLeod, 1973), but probably not nearly as much as grasses would (Majumdar, Momin and Kehar, 1967). Actually, Leigh, Wilson and Mulham (1978) have shown that seasonal variation played a minor part in determining browse quality of four Australian fodder trubs. Pal et. al (1979) processing the information on chemical composition of 26 species of fodder trees from Himachal Pradesh, India, found that average crude protein content was significantly higher in April (16.7%) than in August and December (14.7 and 14.3% respectively).

As mentioned, laboratory analyses may be of limited value in assessing fodder nutritive value. As is well known, the Weende system may not reflect the availability of cell-wall constitutents, which may be hindered by a high lignin or silica content (Van Soest, 1969). A high protein content may not, therefore, necessarily represent a potential protein supplement. Nevertheless, data compiled in Table 3 would indicate that actual protein digestibility of fodder trubs does not differ considerably from that estimated by a widely accepted regression equation for digestible crude protein on crude protein (McDonald, Edwards and Greenhalgh, 1973). On the average, for the 38 sources measured, digestible crude protein would be only 90% of that estimated, but the range of values (34 to 127%) would suggest large variations between trub species.

But even digestibility may not be a good indicator of nutritive value. Experimenting with dried leaves of 4 shrub and 4 tree species Wilson (1977) found that those of higher digestibility were eaten sparingly, there being no correspondence between digestibility and organic matter intake, probably as a consequence of unpalatability factors. In a recent review on the nutritive value of Australian browse plants Wilson and Harrington (1980) go even further, stating that 'There are no browse species of both high quality and high palatability and perhaps we should not expect them to be (because they will succumb to over-browsing)'. Ibrahim (1981) discusses different plant and animal factors affecting palatability.

Information on pod digestibility seems to be rather scarce. The one available on *Prosopis juliflora* (Kargaard and van der Merwe, 1976) shows that when used as the only source of feed dry matter digestibility (DMD) was 65%, while that for crude protein was 67.2%. It should be mentioned that pods were hammer milled, otherwise seeds may pass undigested through the digestive tract. For *Ceratonia siliqua* Charalambous (1966) reports a DMD of 82.6% and a CPD of 80.1% from sheep digestibility trials carried out by others. Toxicity may be another factor limiting the nutritive value of fodder trubs. The toxic effect of mimosine contained in *Leucaena leucocephala* has been known for years (Brewbaker and Hylin, 1965). The alkaloid could significantly affect animal response (Holmes, 1981), which may be alleviated through mineral supplementation (Jones, Blunt and Nurnberg, 1978) or, better still, by breeding low mimosine cultivars (Winter and Jones, 1980).

Table 3. Protein Digestibility of fodder trubs

Trub species	Animal	1 Crude Protein CP (%)	2* Estimated CPD (%)	3 Measured CPD (%)	3/2 (%)	References
Prosopis cineraria	Sheep	14.2	65.3	22.0	33.7	Bohra, 1980
	Goat	14.2	65.3	38.9	59.6	Bohra, 1980
Ficus religiosa	Cattle	14.0	64.9	56.6	87.2	Mia *et al.*, 1960
	Goat	14.0	64.9	54.3	83.7	Mia *et al.*, 1960
Ficus religiosa	Cattle	11.9	60.3	58.3	97.0	Ram & Ray, 1943
Ficus infectoria	Cattle	9.6	52.9	56.0	105.8	Ram & Ray, 1943
Zizyphus jujuba	Cattle	8.6	48.5	35.5	73.2	Ram & Ray, 1943
Ailanthus excelsa	Sheep	16.2	68.5	80.2	117.1	Bhandari & Gupta, 1972
Zizyphus nummularia		14.1	65.1	53.5	82.1	Nath, Malik & Singh, 1969
Atriplex vesicaria	Sheep	12.5	61.8	71.4	115.5	Wilson, 1977
Atriplex nummularia	Sheep	20.6	73.3	82.0	111.8	Wilson, 1977
Mayreana pyramidata	Sheep	13.1	63.1	55.1	87.3	Wilson, 1977
Bassia diacantha	Sheep	12.5	61.8	49.3	79.8	Wilson, 1977
Acacia pendula	Sheep	16.9	69.4	63.2	91.0	Wilson, 1977
	Goat	16.9	69.4	68.8	99.1	Wilson, 1977
Casuarina cristata	Sheep	9.4	52.1	22.1	42.4	Wilson, 1977
	Goat	9.4	52.1	32.3	62.0	Wilson, 1977
Grewia elastica	Goat	19.9	72.7	71.2	97.9	Khajuria & Singh, 1968
Ficus bengalensis	Cattle	9.6	52.9	20.0	37.8	Mia *et al.*, 1960
	Goat	9.6	52.9	42.5	80.3	Mia *et al.*, 1960

Table 3. (Continued)

Trub species	Animal	1 Crude Protein CP (%)	2* Estimated CPD (%)	3 Measured CPD (%)	3/2 (%)	References
Albezzia lebbeck	Cattle	20.1	72.9	64.5	88.5	Khajuria & Singh, 1968
Albezzia lebbeck	Sheep	16.8	69.3	65.0	93.4	Gupta, 1980
Atriplex nummularia	Sheep	21.7	74.2	78.0	105.1	Wilson, 1966
Atriplex nummularia	Sheep	17.0	69.6	83.0	119.3	Wilson, 1966
Atriplex vesicaria	Sheep	18.4	71.2	74.0	103.9	Wilson, 1966
Atriplex vesicaria	Sheep	11.1	58.1	71.0	122.2	Wilson, 1966
Kochia pyramidath	Sheep	15.1	66.8	57.0	85.3	Wilson, 1966
Antiaris africana	Cattle	12.1	60.8	77.5	127.4	Mabey & Rose Innes, 1966
Grewia carpinifolia	Cattle	15.8	67.9	77.8	114.5	Mabey & Rose Innes, 1966
Baphia nitida	Cattle	23.1	75.3	72.3	96.1	Mabey & Rose Innes, 1964
Griffonia simplicifolia	Cattle	18.6	71.4	81.4	114.0	Mabey & Rose Innes, 1964
Ficus glomerata	Goat	11.2	58.4	59.7	102.2	Majumdar & Momin, 1960
Morus indica	Cattle	11.5	59.2	68.6	115.8	Rao, Kumar & Sampath, 1971
Mellotus philippensis	Sheep	14.5	65.8	53.2	80.8	Bhargava, Katiyar & Saxena, 1977
Brachychiton populneum	Sheep	14.6	66.0	75.8	114.8	Norton *et al*, 1972
Acacia aneura	Sheep	14.9	66.5	63.1	94.9	Norton *et al*, 1972
Zizyphus nummularia	Sheep	10.5	56.2	33.1	58.9	Singh & Gupta, 1977
	Goat	10.5	56.2	36.2	64.4	Singh & Gupta, 1977
Bamboosa arundinaceae	Sheep	18.6	71.4	72.4	101.4	Sharma, Chawla & Negi, 1968
Bauhenia variegata	Sheep	13.8	64.5	36.0	55.8	Sharma, Chawla & Negi, 1968
Sesbania aegyptiaca	Goat	19.5	72.3	80.8	111.7	Singh, Kumar & Rekib, 1980

*Calculated as Digestible Crude Protein (DCD)/Crude Protein Content (CP), DCP being estimated as: % DCP = (% CP X 0.9115) – 3.67

Trials assessing the potential of fodder trubs in terms of animal production are rather scarce. The use of *Leucaena* sp. as protein supplement is probably the best documented. A recent review by Jones (1979) indicates that, for beef fattening, effects are comparable with those derived from concentrated protein sources, when limited amounts are offered. Under grazing conditions the wide range in daily gains recorded (0.29 to 0.93 kg) was attributed by the same author to environmental factors influencing Leucaena growth and mimosine content, as well as to the intake of Leucaena and the corresponding alkaloid level. In the same review Leucaena was found to improve milk production, but also tainted the milk produced; this can be reduced by preventing cows from browsing Leucaena for several hours before milking. When Leucaena was substituted for a commercial ration for growing pigs, Malinycz (1974) found that weight gain and feed conversion ratio were adversely affected at levels higher than 20 per cent. Results of studies with chenopodiaceous shrubs are somewhat controversial. Those of Leigh, Wilson and Williams (1970) indicate that these shrubs are of little or no value in reducing seasonal fluctuations in wool growth when growing in an established perennial grassland pasture. Their low contribution may stem from shrubs not being consumed when grass is available, and from their limited value as protein supplements when pastures contain an acceptable nitrogen level. Leigh, Wilson and Mulham (1968) report that *Kochia aphylla* contributed a maximum of 2% of the diet at low and 7% at high stocking rates in autumn, when crude protein content in the selected diet was well above 12% at both stocking rates. Although Kochia has been shown to have a higher palatability than *Atriplex* and *Artemisia* (Nemati, 1977) it is probably not the relative value among shrubs that matters, but the one to the adjacent pasture. Eyal, Benjamin and Tadmor (1975) also found that sheep performance was lower when unimproved native pasture in the 200–400 mm rainfall belt of southern Israel was substituted by 1600 *Atriplex halimus* ha^{-1}. On the other hand, a comparison between the productivity of sheep and cattle browsing/grazing a semi-arid *Atriplex vesicaria* community over a 4-year period (Wilson and Graetz, 1980), showed that liveweight gain ha^{-1} $year^{-1}$ was 12.9 and 19.4 kg for cattle and 13.4 and 20.1 kg for sheep under low and high stocking rates respectively (11.7 and 17.5 ha/cow and 1.7 and 2.5 ha/ewe).

Experiments using *Glyricidia maculata* as a supplement to *Brachiaria brizantha* in the diet of milking cows indicate that incorporating the tree foliage in proportions of 50 and 100% of the diet produces liveweight gains of 14 and 10 kg cow^{-1} in a month and yields of 6.6 and 7.6 lt milk cow^{-1} day^{-1} respectively, as compared to a loss of 12 kg and a production of 5.8 lt when cows were given grass alone (Chadhokar and Lecamwasam, 1982). Reservations on the experimental methodology throw some doubts on the conclusiveness of these findings, but nevertheless suggest the high fodder potential of Glyricidia. More reliable evidence of this potential was provided by Chadhokar and Kantharaju (1980) when Glyricidia was used as a supplement to *Brachiaria miliiformis* in the diet of pregnant ewes. Proportions of 25, 50 and 75% of Glyricidia in the diet increased lamb survival from 33 (no Glyricidia) to 75, 71 and 100%, and lamb weight at 15 wks from 5.4 to 9.9, 10.0 and 11.0 kg respectively. Using *Glyricidia sepium*, Carew (1980) found that sheep and goats fed for four months made a liveweight gain of only 30 and 14 g day^{-1} respectively, despite a DMD of 66%, a CP content of 26.1% and a dry matter intake of 3.2 and 3.1 as percent of metabolic body weight. Although a closer analysis shows an adaptation period of 9 weeks, after which liveweight gains were of the order of 64 and 25 g day^{-1} for sheep and goats respectively, the slow rates would suggest a mineral deficiency.

Available information would indicate, therefore, that of the major nutritive components in a ruminant diet foliage from fodder trubs should be mainly considered as a source of protein. Fruits, particularly pods from legume trubs, could be used as both energy and protein supplements, provided that seed protein is made digestible through mechanical treatment.

The literature reviewed on the role of fodder trees and shrubs in animal production under rangeland conditions would suggest that:

– several species have been identified for different ecological zones, which are potential sources of fodder;

– although dry matter productivity from the foliage of trubs seems to be rather small, its reliability in bad years and its presence during dry seasons makes it particularly valuable; while pod producing trubs may become a very useful source of energy and protein concentrate;

– protein supply appears to be the main nutritive role of trubs, which could be limited by low intakes;

– there is a need to undertake studies evaluating the animal production potential of fodder trubs vis-a-vis alternative sources.

2.2 *Forest grazing*

This has been defined as 'any situation where trees (meaning timber producing ones) and grazed pasture are grown together as an integrated management system, the prime objective being to increase long term net profit per hectare'. However, such a system may have a quite different meaning according to the manager. As McQueen, Knowles and Hawke (1976) put it, 'To the forester it may be a question of growing pasture under trees as an alternative source of intermediate income to production thinning for posts or pulpwood. It has other attractions for foresters, such as greatly improved access for pruning and thinning, and reduced fire risk. The farmer, on the other hand, regards forest farming as the growing of tree crops on pasture land for a long-term investment with the minimum of prejudice to current farm production. Forest grazing can be seen as a complete production system, perhaps comparable with grain and fat lamb farming systems, rather than as an opportunist

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Table 4. Comparison of yield data, treatments 1 and 6, Mungalup experiment (McKinnell, 1979)

Age	Treatment 1			Treatment 6		
	spha	Yield (m^3 ha^{-1}) Pulp	Saw	spha	Yield (m^3 ha^{-1}) Pulp	Saw
8.2	1108	–	–	500	76.6	–
12.6	1108	–	–	250	133.1	–
19.5	500	114.5	59.3	125	18.0	196.4
Standing volume at age 26.5 years (m^3 · ha^{-1})		110.0	429.3		17.5	304.0
Total volume produced (m^3 · ha^{-1})		224.5	488.6		245.2	500.4

enterprise. Accordingly, in research as in practice, it is necessary to place equal emphasis on both the agricultural and the forestry aspects'.

Forest grazing is practised as a commercial system in Australia (Borough, 1977), Britain (Adam, 1975), Fiji (Bell, 1981), New Zealand (Tustin and Knowles, 1975), USA (Burton, 1973; Knowles, 1979) and it has been suggested as an alternative form of land use for the Amazonia (Kirby, 1976). A comprehensive overview of the technology as practised in Australia has been published by the CSIRO (Anonymous, 1978), and a list of most relevant references has been put together by ICRAF (1981).

Results from economic analysis of forest grazing are somewhat contradictory. Borough and Reilly (1976) carried out a theoretical analysis of three alternative strategies, namely: 1) grazing beef cattle on improved pastures (beef strategy of BS); 2) radiata pine plantations (RPS); and 3) combined beef grazing and radiata pine plantations (FGS). Pulpwood and sawlogs were assumed to be produced from the RPS and FGS over rotations of 30 and 25 years respectively, and two levels of log prices were examined. Results in terms of the Present Net Worth (or the sum of the discounted returns and discounted costs over one rotation) showed the RPS to be the most profitable alternative ($231 and 368 ha^{-1} for low and high sawlog prices respectively), followed by the FGS ($224 and 347) and the BS ($101). In discussing the small difference between RPS and FGS, the authors assumed that early returns from pasture and beef and the additional value added to sawlogs due to early thinning and pruning in the FGS apparently offset the bulk of the losses induced by the pruning and thinning operations. They conclude that if some allowance is made for the riskiness of the three alternatives the farmer would almost certainly opt for the FGS (Forest Grazing Strategy).

The assumption of Borough and Reilly (1976) that wider spacement in FGS does not affect the yield of sawlog has been substantiated by McKinnell (1979). The data in Table 4 indicate that total volume of timber produced under two thinning regimes of radiata pine planted in 1957 was not significantly different.

However, it should be stressed that the larger branch diameter induced by wider spacement of the FGS required a strictly timed pruning of the limbs up to 10 m from the ground, otherwise large knots would have affected wood quality. The labour and equipment necessary for this kind of operation may become an economic drawback in the application of such a system. (Using other trees with self pruning properties would be particularly relevant, like *Jacaranda copaia* in the lowland humid tropics, which wood is being used for ship board manufacturing in the Peruvian Amazon). Nevertheless, an economic analysis carried out by Gisz (1978) challenges the results obtained by Borough and Reilly (1976). Results show that assuming a 25 year rotation the internal rate of return for a FGS would be 16.1%, while that of a sheep only strategy would reach 22.1%. On the other hand, Knowles (1975) arrived at the conclusion that the financial return from a sheep grazing operation would be \$66.1 ha^{-1}, while those from a forest grazing system would be \$84.9. In this paper he discusses some factors the farmer should consider in evaluating a forest grazing approach, such as farm size and stocking rate, farm location and plot size.

Practices to be followed in implementing a forest grazing system seem to have reached a 'prescription' stage, at least for the combination of *Pinus radiata* with improved pastures in the temperate zones of Australia and New Zealand.

On the establishment of trees (*Pinus radiata*) on pasture the recommended technique is to apply *Paraquat-simazine* as spots or strips before planting. For 1 and 1.5 year-old-seedlings, growth rate at 18 months was 29 and 33% faster respectively when the herbicide was used than when it was not (Tustin, 1974). On the effect of browsing damage to trees, studies indicate that growth rate is affected by 10% when tree leaders are browsed in the first spring only, by 34% when leaders are browsed in the first spring and autumn, and by 46% when in addition to that they are browsed in the second spring (Tustin, 1975). However, cattle display a marked propensity to browse and debark trees, so it is preferable to use sheep, which can be introduced from the second year onwards. According to Tustin, Knowles and Klomp (1979), a suitable grazing system for both weaned lambs and older sheep is to stock at 12–25 animals ha^{-1} in autumn (March) so that the pasture is eaten out by early spring (August/September), and then to remove the sheep for 3–4 months to prevent browsing during the critical spring period. In the intervening period hay or silage cropping is advocated (Gillingham, Klomp and Peterson, 1976). It is interesting to note that no mention is made of a 'taungya' alternative, which appears as biologically feasbile and economically viable (establishing trees in combination with food crops, which are substituted by pastures when trees are out of reach of animals). Cattle should not be introduced until trees are more than 4 m high.

The recommendation on silvicultural management calls for planting pines in improved pasture at 2 x 5 m spacing (1000 trees ha^{-1}; thin at age 5 to

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500 trees ha^{-1} and pruning the remaining trees to 30% of height; prune trees to 40% tree height at age 8; thin to 200 trees at age 12 and prune remaining trees to 50% of height; and finally clearfell trees at age 25 (Knowles, Klomp and Gillingham, 1973). Livestock carrying capacity will be negatively related to tree age. If it is considered 100 when trees are 3 year-old, it will be reduced to 90 when they are 4, 80 when 5, 50 when 11 and 10 when 18 (Forest Research Institute 1978).

Available information would suggest that forest grazing is a technically feasible alternative, its economic viability depending on the technical and economic potential of the timber tree and the livestock enterprise, as well as the duration of the production cycle and access to the financial capital.

2.3 Plantation grazing

Intercropping of tree crops, particularly coconuts, for increasing agricultural production in the tropics is an old practice. The application of multiple cropping principles can produce substantial amounts of additional crops without impairing coconut yields and the fertility of the soil (Ramachandran Nair, 1979). Only intercropping of tree crops with pastures for animal production will be considered under this topic.

2.3.1 Coconut plantations. A comprehensive and updated review of all aspects related to managing pastures and cattle under coconut can be found in the book by Plucknett (1979). An annotated bibliography containing 328 references has also been prepared by Reynolds (1978a). In a recent review Reynolds (1980) concluded that the grazing of cattle on improved pastures under coconuts results in extra income from the sale of animal products and increased returns from copra, although he admits that debate about which crop to establish under coconuts will continue. Although pasture establishment costs as estimated by Reynolds (1980) appear quite high (US\$128 ha^{-1}), they would be compensated by returns from beef (US\$97 to 153, depending on the pasture species used), particularly considering that maintenance costs after establishment are in the order of US\$35 ha^{-1} yr^{-1}.

The main factor governing the intercropping of pastures and coconuts is the shading effect of coconut trees. Figure 1 shows that pastures could only thrive under young and mature stands.

Under such condition shade tolerance of grasses appears as one of the most important factors for a successful combination.

In Western Samoa Reynolds (1978b) compared the production of native pastures with that of 15 species growing under coconuts allowing approximately 50% light transmission. Two *Panicum maximum* varieties were ranked within the top production level group (14–16 t of DM ha^{-1} yr^{-1}), followed by another *P. maximum* (var. Embu, or Creeping guinea) and *Brachiaria*

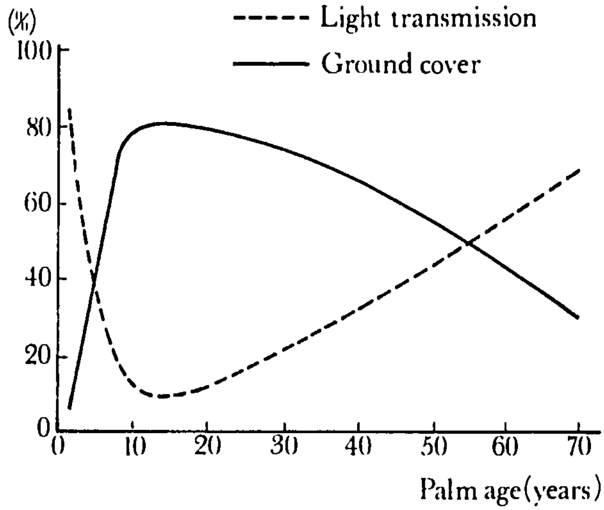

Figure 1. Effect of stand age on light transmission (Nelliat, Bavapa and Nair, 1974).

humidicola in the 10–14 t group. Production from local pastures was in the order of 8 t ha^{-1} yr^{-1}.

These results have been somewhat challenged by experiments in the Solomon Islands, where mean light transmission was 30.7%, but actually 43% of the area under coconuts received less than 10% of the outside intensity (Steel and Whiteman, 1980). All ten grasses evaluated showed a general pattern of declining yield with time, dropping from a level of 1120 kg DM ha^{-1} at first harvesting to approximately 200 kg in the second year. In the first year *P. maximum* cv. Embu and *Brachiaria miliiformis* were the highest yielding, but both suffered considerable insect damage and failed to recover, while *B. brizantha* gave the highest yield in the second year after a poor establishment. Results suggested that where *Axonopus* sp. (a naturalized grass) is already established there may be little advantage in planting introduced species.

A possible explanation of these apparently contradictory results may lie with the applied level of management. As a result of experiments carried out over nearly four years on pastures under coconuts with 50–80% light transmission in Western Samoa, Reynolds (1981) concluded that when low management levels are employed *Ischaemum murinum* would give a moderate increase in animal production over local pastures, possibly offset by a slightly adverse effect on coconut yields. For better management levels fertilized *Brachiaria miliiformis, brizantha* and *humidicola* offer considerable increases in forage production, liveweight gains and possibly coconut yields.

The inclusion of legume species in the sown pasture seems not only to increase the carrying capacity but also coconut yield. Experiments in Bali, Indonesia, show that a mixture of grass and legume species (where *Brachiaria decumbens* and *Centrosema pubescens* were the most successful) was able to produce 733 kg ha^{-1} of liveweight at 6.3 beasts ha^{-1}, and to increase nut yield and weight by more than 50% when compared to the volunteer pasture (Rika, Nitis and Humphreys, 1981).

2.3.2 Rubber plantations. Wan Embong (1978) has proposed the application of an integrated farming concept to rubber smallholdings, where livestock will play a role after food intercropping becomes uneconomical due to shading in the interrow. Under these circumstances two livestock enterprises appear possible: poultry and small ruminants.

Poultry rearing is actually based on the utilization of feed either purchased or produced outside the plantation. This is only used as a place to build the housing facilities for poultry and to supplement concentrate feeding with grasses and herbs growing underneath rubber trees. Profitability of the poultry enterprise has been shown to range between 16 and 26%, depending mainly upon the cost of feed (Lee, Ng and Goh, 1978).

Interaction with the tree components comes mainly as a result of both 'weeding' of the plantation by the roaming chickens and 'manuring' via poultry droppings. Wan Embong and Yan Kuan (1976) reported that in an 18-month period the average girth increment of rubber trees in the plot where poultry were reared was 12% higher than in control trees. Wan Embong (1977) has also studied the potential of sheep rearing under rubber. Forage dry matter yield of the natural vegetation (composed of grasses, broad leaves and ferns) was in the order of 500–600 kg ha^{-1}, 60 to 70% of the components being suitable for ruminant feeding with a crude protein content of 10–11%. Performance of sheep grazing this vegetation was found to be comparable to 'normal' rearing, but unfortunately no carrying capacity data were provided. As in the case of coconut, there is certainly scope for improving the quantity and quality of fodder growing underneath rubber trees by substituting introduced species for natural vegetation.

2.3.3 Cashew plantations. As a result of experiments carried out in the coastal zone of Kenya, Goldson (1980) concluded that milk production from cashew pastures can be equal to that from open fields, although it should be stressed that pasture availability was never a limiting factor. The main beneficial effect of the cashew trees appear to be the provision of shade and comfortable conditions to anmials, under which they could spend a longer grazing time. The indirect effect through the pasture was apparent at certain times of the year, but it was not directly proved.

Grazing under tree crop plantations appears, as in the case of forest plantations, a technically feasible and economically viable alternative land management system. Conclusions reached by Thomas (1978) in his review appear still to be valid ones, when he says that: 'Of the three tree crops considered (rubber, oil palm and coconut), the greatest opportunity for pasture establishment and livestock integration exists within mature coconut plantations where tall unimproved strains are grown. Pasture growth would not be severely limited by low light intensity and there would be no competition for light detrimental to the coconut. However, there is a need for more quantitative information on the comparative productivity of grasses, legumes and grass-legume mixtures under coconuts and the effects of different stocking rates and grazing systems'.

3.The service role

There are many service roles trees can play and a comprehensive review of them is beyond the scope of this paper. Discussion will therefore be limited to those roles considered more relevant for silvopastoral systems, i.e., those affecting productivity of the understorey vegetation, providing shelter, and functioning as living fences.

3.1 Overstorey-understorey relationships

An analysis of relationships occurring in the arid and semi-arid zones is given by Shankar (1981). Ffolliot and Clary (1972) produced an annotated bibliography with 262 references covering mainly interactions that take place in the rangelands of North America.

Most of the literature from the temperate zones reports a negative relationship between tree basal area and herbaceous forage produced in the same unit of land. Under the coniferous forests of North America McConnell and Smith (1970) and Grelen, Whitaker and Lohrey (1972) reported a linear relationship, where canopy percentage or tree basal area accounted for 94 and 58% of the variation in herbage yield respectively. Pase (1958) established a logarithmic relationship and Jameson (1967) and exponential one. In an interesting analysis of the causal relationship between forest density and herbage production in a Pinyon-Juniperus community on two different types of soil, Jameson (1966) found that in all cases litter, and not basal area, was the most important factor influencing blue grama production. As expected, the negative effect of tree basal area on herbage production also negatively affects the carrying capacity of the range (Clary, Kruse and Larson, 1975). Studies on Mulga (*Acacia aneura*) communities in Australia have shown similar relationships (Beale, 1973 and Pressland, 1976). In the same zone and in woodlands dominated by *Eucalyptus populnea*, Walker, Moore and Robertson (1971) had also found that the relationship between herbage weight and woody plant density consistently had the same form and closely fitted a transition sigmoid curve. However, when tree-grass relationships were analyzed on an individual basis (as opposed to per unit of land) Christie

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(1975) found that the yield of *Cenchrus ciliaris* from the microhabitat under *Eucalyptus populnea* was much higher than the one from the inter-tree areas (300 and 107 g/m^2 respectively). This increase, attributed mainly to higher pH, phosphorus and potassium levels (Ebersohn and Lucas, 1965), means that 7% of the area (for an average microhabitat area of 700 m^2 with a tree density of 20 ha^{-1}) has the potential to produce around 20% of the total available herbage per hectare. Would the apparent contradiction be explained by the tree density data used to derive the equations?, (which in the case of Pressland's work ranged from 40 to 640). Analyzing the effect of varying density of *Zizyphus nummularia* on grass production Kaul and Ganguli (1963) reported that yield was higher when shrub density increased from 11 to 14% (770 to 875 kg ha^{-1} respectively), but declining to 545 kg when shrub density reached 18%.

Studies on the effect of tree canopies on yield of *Panicum maximum* in semi-arid zones tend to corroborate the beneficial relationships at the microhabitat level. Using data from a sub-tropical 'miombo' savanna on sandy soils with low inherent fertility, Kennard and Walker (1973) found that yields of *Panicum* were highest under open canopy sites (447 g/m^2), followed by those from the open grassland (302 g/m^2) and the closed canopy (276 g/m^2). It was reported that sites under closed and open canopies were associated with a higher rate of water infiltration and a higher water-holding capacity, exchangeable magnesium, calcium, potassium and organic carbon in the soil, while average light intensity and mean surface temperature were lower. These results are supported by data from the sweet bushveld in the Transvaal (Bosch and Van Wyk, 1970). In association with *Combretum apiculatum* the number of *Panicum* plants per square foot outside and inside the canopy were 0.00 and 1.13 respectively. Corresponding figures for *Boscia albitrunca* were 1.00 and 1.52, for *Acacia senegal* 1.00 and 2.87 and for *Acacia tortilis* 2.62 and 3.92. Greenhouse experiments using 'open soils' and 'tree soils' indicated that beneficial effects of the Panicum-tree association are largely due to soil enrichment by trees.

Beneficial effects of tree microhabitat on pasture growth have also been reported for humid zones. Jagoe (cited by Masefield, 1957) showed that in Malasia *Axonopus compressus* gave higher yields and contained higher protein when grown under *Samanea saman* (raintree) and two other leguminous trees, than when grown under non-leguminous trees or in the open. Similar results were found by Daccarett and Blydenstein (1968) in Turrialba, when analyzing the relationship between *Erythrina poeppegiana, Phitecelobium* (or *Samanea*) *Saman, Glyricidia sepium* and *Cordia alliodora* and the *Panicum maximum – Papspalum fasciculatum – Homolepis aturensis – Digitaria decumbens* pasture growing underneath. None of the trees reduced dry matter production significantly, in relation to the unshaded control plot. Protein percentage of the herbage under *Erythrina* was significantly higher than under any other species.

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Differences between tree species in the beneficial effect of their micro-habitat are also apparent in the arid zones. Comparing the yield of *Cenchrus ciliaris* under the canopies of leguminous trees in Rajhastan Shankar, Dadhich and Saxena (1976) found that differences in dry matter production between trees species could differ as much as 287%. Giving a value of 100 for the amount of grass grown under *Prosopis juliflora* and *Acacia senegal* (800 kg ha^{-1}), that under *Albizzia lebbeck* was 163, beneath *Tecomella undulata* 200, and 287 for *Prosopis cineraria*. As mentioned, most of these beneficial effects deriving from a close association between tree and grasses have been attributed to improvements in soil fertility. It is well known that the agro-forestry 'wonder' tree (*Acacia albida*) can increase C, N, available P and Total Exchangeable Cations by 92, 94, 134 and 90% respectively (Charreau and Vidal, 1965). Although the higher nutrient content in soils under *Acacia albida* may in part have been transferred from elsewhere by livestock either taking shelter from the sun or browsing lopped branches (personal observation), it could not explain by itself the recorded level of increase. The genus *Prosopis* has also been associated with higher organic C, total N and available P in soils underneath the canopy (Singh and Lal, 1969 and Tiedemann and Klem-medson, 1973). But soils under *Tecomella undulata* and *Albizzia lebbeck* have been shown to have higher total N than under *Prosopis cineraria* and *juliflora* (Aggarwal et al., 1976). Garcia Moya and McKell (1970) also found in a low fertility desert plant community (mainly *Acacia gregii, Cassia armata* and *Larrea divaricata*) that soil N content decreased significantly as a function of radial distance from the center of the shrub canopy. These findings may be particularly relevent in the light of the predominant role that N may have over moisture availability for plant productivity in semi-arid regions (Felker et al., 1980).

But soil enrichment may not be the only reason for an improved micro-habitat. Tiedemann and Klemmedson (1977) conducted studies in the mesquite-desert grassland to assess effects of shade, roots and litter of mesquite trees on understorey vegetation and microenvironmental factors. They concluded that *Prosopis juliflora* exerted a strong influence on net radiation and soil temperature in the area directly beneath the canopy. This improved conditions for establishment and growth of vegetation compared to surrounding open areas.

Redistribution of rainfall may be another cause for the development of a favourable microhabitat underneath the canopy. A high proportion of the incoming precipitation may be intercepted by the canopy, depending on its structure. Some of the intercepted water is lost to the atmosphere, some falls to the soil surface (throughfall); and some is held by the various canopy surfaces (such as leaf and bark), while the remainder is channelled to the ground by the leaves, branches and stems (stemflow), to penetrate in close proximity to the tree bole. Working with *Acacia aneura* Slatyer (1965) and Pressland (1973) found stemflow to be ecologically important, calculating

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that redistribution of a 25 mm rainfall would amount to 140 mm of rain in the 'area of infiltration' around the trunk.

3.2 Shelter

Of the many uses of shelter only those affecting livestock directly or indirectly (through pasture production) will be discussed here. An extensive bibliography on the effects of environment on livestock has just been published (Stevens, 1982). Although unfortunately it has not been arranged by subject matter but in alphabetical order, the more than 1900 references on the effect of temperature, humidity, wind, thermal radiation, rain, noise and altitude for cattle, swine, sheep and poultry makes it a very valuable document.

Literature on the specific effect of shade trees or tree windbreaks is very scarce. A thesis by Goldson (1973) on dairy production in a cashew-pasture combination in coastal Kenya indicates that the biggest contribution of the trees to the animal was the reduction of solar radiation, reflected on the animal behaviour. However, there was no difference between the milk yields of animals in four treatments with and without shade during the wet and dry seasons.

Under the cold windy weather of New South Wales sheltering lambing ewes from the wind chill by using a tall unpalatable phalaris (not precisely a woody perennial!) reduced mortality of single lambs from 17.5 to 8.9%, and that of multiple births from 51.3 to 35.8% (Alexander et al., 1980).

Shelter of pasture is an important aspect in animal production under grazing conditions. The effect of shelter on the productivity of grasslands was reviewed by Marshall (1967). The effect of artificial windbreaks (sheet iron fences!) on behaviour and production of sheep in adjoining paddocks was studied by Lynch and Marshall (1969), during drought and non-drought years, at three stocking rates. During the drought year increase in sheep body-weight was higher in the sheltered than unsheltered paddocks, ranging from 7.4 to 21.6% in the low and medium stocking rates. Pasture production from the sheltered paddocks was about double that of the unsheltered ones in all stocking rates. Differences in body weight during the rainy years were in the order of 20%, but only for the medium and high stocking rates. Again pasture production was twice as much in the sheltered paddocks than in the unsheltered ones. It was concluded that variation in animal productivity was largely due to differences in pasture availability rather than to an effect of shelter as such. This increase in pasture availability under sheltered conditions may have been due to an increase in soil water availability, as reported by Lynch, Elwin and Mottershead (1980). They recorded soil water in 80 x 30 m paddocks, protected with 1 m high poly-ethylene mesh along the 80 m side, over a dry period of 29 days after soil had drained to field capacity. Significantly less water (12.3 mm) was lost from the two sheltered paddocks, resulting in a higher herbage availability and in an 18% higher metabolizable energy intake by the grazing sheep. Should this beneficial effect of artificial barriers not be offset by the tree-pasture competition in trub windbreaks, these should be considered in environments where there are periods during which water stress is the main factor limiting plant growth.

Wind may also affect pasture growth directly. In experiments where *Festuca arundinacea* and *Lolium perenne* grasses were exposed to constant windspeeds of 1.1, 4.0, 7.4 and 10.0 m s^{-1} m in a wind tunnel for 14 days, Russell and Grace (1978.a and 1978.b) found that increasing windspeed reduced the rate of leaf extension, the relative growth rate and the leaf area ratio. These effects could not be attributed to water stress, for, although leaf conductance increased with exposure to high wind no effect on leaf water potential was detected. Having observed that rate of photosynthesis was not affected either, they concluded that mechanical stimulus itself may have caused the reduction in leaf growth rate.

It has been shown that shading may have an adverse effect upon both growth and chemical composition of pasture species, at least under temperate conditions. When two grasses and two legumes were grown at three illuminances (between 100 and 34%), Ludlow, Wilson and Heslehurst (1974) reported that the relative growth of grasses was more affected than that of legumes, resulting mainly from a greater decrease in net assimilation rate. Shading temperate grasses has been shown to reduce the proportion of soluble carbohydrates, calcium and phosphorus, and increase the proportion of cellulose and lignin (McEwen and Dietz, 1965, and Hight, Sinclair and Lancaster, 1968). However, the known negative effect of temperature upon quality of forage grasses (Deinum, 1966) may lead to a beneficial effect of shading under tropical conditions.

3.3 *Living fences*

The role of woody perennials as components of living fences could be that of providing living poles, on which wire is fastened, or living fences, which would not require wiring. These management tools, specially living fences, acquire particular relevance under grazing/browsing systems, either under arid to semi-arid conditions (where the cost of fencing per head of livestock goes up as carrying capacity decreases), or in the more humid regions (where poles have to be replaced quite often). In an analysis on the economic aspects of browse development in Africa done by ILCA (1980) investments on wire fences appear as one of the most limiting factors affecting the economic viability of browse trub plantations. This author has estimated that for a 30 ha property in the Pucallpa area of the Peruvian Amazon the maintenance of boundary fencing and two internal divisory lines would have an annual cost equivalent to the gross income from a hectare of rice.

Recognizing that the use of trubs as living poles has become a widely diffused technique in various ecological zones of Costa Rica, Sauner (1979) identified 57 species as being regularly planted as components of fences. The 26 most important ones are described in his paper. Looking for a fast growing shrubby plant, easily propagated by cuttings and unpalatable to animals, Calvert and Errington (1975) tried in the New Hebrides four species (*Citrus acida, Bougainvillea, Pandanus* and *Nerium oleander*) with varying degrees of success. Crane (1945) has also described species and methods used in Cuba at that time.

In addition to the species mentioned in the cited references, this author has seen a very impressive 'bull strong, horse high and pig tight' living fence made of bread fruit (*Artocarpus altilis*) in the alluvial plains of the Peruvian Amazon, which serve a double purpose, as fence and as a source of food and pig feed. The use of *Euphorbia* sp. in the medium potential highlands of East Africa by small farmers is a common feature as a single purpose fence. In the Rajhastan desert this author has also seen the use of *Prosopis juliflora* as a double-purpose living fence, which had to be protected during the first few years of development.

Although limited, the literature reviewed serves to indicate the potential for a service role in woody perennials as components of agroforestry systems that include livestock. Moreover, it would suggest the scope for incorporating that role in species playing a productive one.

4. Conclusions

Despite the relative scarcity of information reviewed, it suggests some tentative conclusions to guide research efforts in the field of woody perennials as components of silvopastoral or agrosilvopastoral land management systems.

(i) There appears to be a greater scope for improving the contribution of woody perennials to the so-called browsing systems than to either forest or plantation grazing.

(ii) Improvements in forest and plantation grazing systems would be mainly linked to research on the pasture components (particularly selecting for shade tolerant species), although something can be achieved through silvicultural or horticultural management or by selecting less competitive self-prunning species, if marketable (e.g., *Jacaranda copaia* for the lowland humid tropics).

(iii) It seems that the contribution of woody perennials to browsing systems could be channelled through the foliage-producing shrubby type of plants or the fruit bearing tree type ones, although a clear differentiation between the two types may appear rather arbitrary at this stage.

(iv) Of the two types the fruit-bearing tree one appears as the most promising alternative.

- Their potential for contributing to the quantitative and qualitative fodder availability in the systems seems higher, although available information is not conclusive. In the lowland humid tropics the advantages of *Leucaena* over herbaceous legumes as a fodder source under more intensive systems has to be tested, particularly when the management drawback of toxicity is considered. Under more arid conditions foliage producing shrubs can certainly offer proteinrich dry matter during the dry period, but the palatability factor throws some shadow on their nutritive value.

- Competition with the other source of fodder in the system (associated grassland) would appear to be lower, or even non-existent, for the tree type, while closeness to the ground of the shrubby type would affect not only grass growth but accessibility to herbage of the grazing animal.
- Direct harvesting of shrub foliage would constrain its use to browsers unless lopping is envisaged, with the corresponding increase in labour (probably not in a critical period). On the other hand, ripe fruits (particularly legume pods) are usually relished by both grazers and browsers, although full utilization of their nutrient contents will, in most cases, require mechanical crushing or grinding.
- Harvesting and storing of fruit fodder would be much simpler than for foliage, if there is a need to use it at other times than when fodder is produced.
- Trees appear better than shrubs at providing the auxiliary role of shelter for animals.

(v) Whatever strategy is followed (foliage or fruit) the service role of species (particularly fostering of pasture growing underneath) should be a determining factor in the selection process. Certainly the legume family has definite advantages in this field.

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