LEGUMINOUS TREES FOR SHADE[1]

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ABSTRACT - Use of leguminous trees to provide shade, especially in perennial crops, would appear to be an ancient agricultural practice, probably coinciding with the domestication of perennials such as tea, coffee and cocoa. Leguminous trees can also be found in association with annual crops, in pastures, and in situations such as living fenceposts, where shade is not clearly being provided to an associated species. The factors which might influence the choice of leguminous as opposed to non-leguminous trees to provide shade in such situations are considered. Various such associations are described in some detail, in an attempt to elucidate some of the ecological interrelationships that are probably reflected in traditional agroforestry practices. It is concluded that not only the possibility of improving nitrogen nutrition but also other characteristics, such as type of shade, coppicing ability and ease of husbandry, might have favored the selection of leguminous trees for shade. Many of these areas would appear to merit considerably more research with the objective of obtaining more quantitative data than is presently available.

Index terms: N_2 fixation.

LEGUMINOSAS ARBÓREAS PARA SOMBREAMENTO

RESUMO - O uso de leguminosas arbóreas, no sombreamento de culturas perenes, é uma prática agrícola antiga, provavelmente coincidindo com a domesticação de plantas perenes, tais como: o chá, o café e o cacau. As leguminosas arbóreas podem ser também encontradas em associações com culturas anuais, em pastagens, e em situações como moirões vivos, onde a sombra não é necessariamente importante à espécie associada. Os fatores que influenciam a escolha de leguminosas, ao invés de não-leguminosas, para o fornecimento de sombra em tais situações, são considerados. Várias associações são descritas em detalhe, numa tentativa de elucidar algumas das inter-relações ecológicas, provavelmente refletidas nas práticas agroflorestais tradicionais. Foi concluído que não apenas a possibilidade de aumentar a disponibilidade de nitrogênio como também outras características, tais como: o tipo de sombra, capacidade de rebrota, facilidade de manejo, devem ter favorecido a seleção de leguminosas arbóreas para sombreamento. Muito destes aspectos merecem maior atenção da pesquisa, com o objetivo de obter mais resultados quantitativos do que os presentemente disponíveis.

Termos para indexação: fixação de N_2.

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INTRODUCTION

A shade tree could be defined as one used to reduce radiation (light and heat) to some part of the environment. Due to the fact that a tree rather than some inanimate object is used to produce shade and that the environment usually includes growing plants and animals, a complex interaction is set up between the environment, the shade trees and the shaded species which extends far beyond the more reduction of heat light (Willey 1975).

We shall first briefly describe the effects of shade per se and then proceed to a discussion of how the situation is altered when a tree is used to produce the shade. Finally, we shall consider the special case which is the object of the present discussion: the effect of using a leguminous tree for shade.

THE EFFECTS OF SHADE

Considering first the environment when no living species is associated with the shade, the primary result of the shade will be to reduce soil and ambient temperatures. Reduced temperature will reduce evaporation from the surface and increase the relative humidity of the environment. Reduced temperature will reduce the reaction rates of physical and biological processes at or below the soils surface (Willey 1975).

When plants or animals are placed in a shaded environment, the effects of reduced temperature become more complex. Reduced temperatures will reduce stress for animals in hot climates, especially those unadapted to such climates. They will also probably induce a modification in activities. However, the increase in relative humidity brought on by reduced temperatures may have adverse effects.

Shading will obviously reduce the light available to plants. The effect of shade on plant growth has been the object of numerous experiments, reviewing which Grime (1979) reached the following conclusions:

1. In response to shade, the majority of plants produce less dry matter, retain photosynthate in the shoot at the expense of root growth, develop longer internodes and petioles, and produce larger thinner leaves.

2. Species differ considerably both with respect to the magnitude and rate of these responses. However, the capacity to maximize dry matter production in shade through modification of the phenotype is most apparent in species characteristic of unshaded or lightly shaded environments while plants normally found in deep shade tend to grow slowly and to show much less pronounced morphogenic responses to shade treatment (Grime 1979).

Economic plants most commonly grown under shade are coffee (*Coffea arabica* L.), tea (*Camellia sinensis* L.), cocoa (*Theobroma cacao* L.), black pepper (*Piper nigrum* L.), vanilla (*Vanilla planifolia* L.), the species of the Zingeberaceae (ginger, cardomom and turmeric) as well as tobacco (*Nicotiana tabacum* L.) for cigar wrappers. As expected, in the wild state, all of these species with the exception of tobacco, occur as understory plants in a tropical forest environment (Purseglove 1968). Willey (1975) reviewed several investigations in which coffee and cocoa leaves were to some degree able to compensate for the reduced light produced by shading by reflecting less light, increasing the chlorophyll content, reorienting the chloroplasts to give less transmission and better utilization of incident light, and increasing the number of stomata per unit of leaf surface. Reduced light has been shown to reduce the intensity, if not the duration, of "flushing" in cocoa. Changes in the chemical composition of leaves due to shading are of special importance in tea, where the leaf is the harvested product. Recent work has shown that shade might adversely affect tea quality (Hilton 1974).

While most researchers agree that reduction of light intensity by shade reduces photosynthesis and probably yields, reduction in leaf temperature and especially reduction in the diurnal variation of leaf temperature caused by shading is generally accepted as beneficial in cocoa, coffee and tea (Willey 1975). The benefits of reduced soil temperature may be of additional importance at the seeding or establishment stage but no experimental evidence was found by Willey (1975). Increased relative humidity occasioned by reduced temperature appears to improve water balances (Fordham 1971) by reducing transpiration.

Before considering the difference in the situation where the shade is produced by trees, two consequences of reduced light intensity should be mentioned. Firstly plants that grow less due to reduced photosynthesis will yield less but will also take up smaller amounts of essential nutrients. At low nutrient levels, shaded cocoa (Murray & Nichols 1966) and tea (Wight 1958) may even outyield nonshaded plants. Other workers have found higher yields for non-shaded cocoa even without fertilizer (Willey 1975) but this will depend on the fertility level of the soil involved. In any case, shading can keep the yield level down to a level that the fertility status of the soil can maintain (Hardy 1962). In coffee, shading also equalizes yields over years of overbearing and subsequent dieback (Huxley 1970). Thus, for farmers without access to high levels of mineral fertilizers, shade can be of considerable value (Beer 1982).

Secondly, shade will alter the ecological balance between the crop and its associated pests, weeds and diseases (Willey 1975). In some cases, this alteration has been shown to be of benefit to the crop as in the case of the cocoa capsid, the coffee leaf miner, and various weeds in pastures. In other cases, shading may favor certain pests and diseases.

TREES FOR SHADE

When shade is provided by trees, the situation becomes complex, mostly because one is dealing with a plant that is photosynthesizing and transpiring rather than merely providing shade. Since they are photosynthesizing, shade trees will affect the quality as well as the quantity of transmitted light. In transmitted light, i.e., that which actually passes through leaves of the shade tree, most of the wavelengths used in photosynthesis are filtered out by the chloroplasts of the leaves of the shade species (Willey 1975). Thus, the understory crop will depend to a great degree on the light which passes through the shade tree leaf canopy without being used for photosynthesis. The distinction often made in the literature between light and heavy shading thus takes on considerable significance although it is rarely specified as whether "light shading" means a fairly uniform sparce leaf canopy or a small number of widely spaced but very large shade trees (Willey 1975). The leaf architecture (size and dispersion) of the shade tree should have a great effect on how much radiation is transmitted with loss of quality and how much is sunflecks, i.e. light which comes through the shade with little or no reduction in quality. Other complicating factors will be wind speed, cumulus clouds, and the effect on photoperiod of the light of altered quality (Allen et al. 1976). It would seem that a so-called "dappled" shade, with abundant sunflecks, which changes with movement of the shade tree leaves would be of greatest benefit to the shaded crop since the other benefits of shading would be maintained (Willey 1975).

Whether transpiration by the shade tree increases water stress to the associated species is one of the most controversial aspects of the use of shade trees (Willey 1975). Again, the effect cannot readily be separated from the reduced evaporation and transpiration in the associated crop induced by the shade. In very humid environments, such as those frequently used for the production of cocoa and tea, the transpiration of the shade tree is probably of little effect and the transpiration of the shade tree may even remove excess moisture in low-lying, high water table areas (Cadima Zevallos & Alvim 1967). When moisture is more limiting, there are frequent reports of shade trees increasing moisture stress (Franco & Inforzato 1951). Willey (1975) puts considerable emphasis on the mass and distribution of roots in the shade and shaded species. Deciduous shade species or pruning shade trees in the dry season would reduce moisture loss in the dry season, but the other benefits of shading would also be lost in this period.

Evaluation of the effects of shade trees on nutrient availability is complicated by the fact, pointed out earlier, that shade reduces growth and nutrient requirements of the associated species. The benefits of the abundant (up to 5,000 $kg/ha^{-1}/yr^{-1}$) of leaf litter generally produced by most shade species is generally recognized although Willey (1975) makes some qualifications to these advantages:

1. The benefits to soil temperature and erosion control of the litter are critical in an environment which is already shaded.

2. Except for the case where the shade trees bring up nutrients from lower levels or fix nitrogen, the leaf litter merely recycles nutrients which theoretically should have been available to the associated species, if over a longer time period.

3. Most of these benefits could also be obtained by mulching.

It would appear to these authors that these qualifications have more theoretical than practical significance. The nutrients in the litter are much more readily available to the associated crop than dispersed in the soil where they can be readily lost by leaching. Mulching requires the added expense of transporting the mulch material and, in any case, the effects of shading are lost.

Some other effects of shade trees which were enumerated by a series of papers by Budowsky (1959, 1981a, 1981b, 1981c, 1982) and Beer (1982) include:

1. Damage to the understory crop by falling or pruned branches of the tree shade (Purseglove 1968).

2. Effect of shade trees on wind velocities, reducing evaporation from the leaf surfaces of the shaded species, but also perhaps promoting condensation which may be of value in dry periods.

3. The shade trees may produce an economic product, which might result in spreading labor use over a longer period.

4. Reduction of damage due to hail and heavy rain.

5. Concentration of raindrops, increasing erosion hazard, which should be offset to some degree by the effect of trees on reducing raindrop impact.

6. Difficulties in harvest, especially mechanized harvest, occasioned by the presence of a shade tree in the associated crop.

7. Use of shade trees results in a more complex environment, more difficult to study and manage efficiently (Budowski 1981b).

LEGUMINOUS TREES FOR SHADE

In considering the special case, in which shade is provided by a member of the Leuminosae, four different uses of shade will be discussed separately, depending upon the type of fauna and flora associated. Some of the considerations discussed under one use will, in many cases, also be of relevance for another use.

The categories we have chosen are as follows:

a. Shade for perennial crops.

b. Shade of animals and/or pasture species.

c. Association with annual crops, including alley cropping.

d. Situations in which there is no obvious associated species.

There would include the provision of shade as an amenity, and the use of leguminous trees for windbreaks, firebreaks and living fences.

a. Shade for perennial crops

Most of the tree species used for shade in perennial crops are legumes. All but one of the species listed by Purseglove as shade for tea are legumes. Of the six genera listed for cacao shade, four are legumes. Although only four of the nine general listed as permanent coffee shade are legumes, most of these are used in East Africa, while in the Americas leguminous shade species predominate. All of the five genera Purseglove lists as temporary shades are legumes. In the case of black pepper, it is most common to plant the vines in existing plantations of other economic species; where shade trees are planted especially for the pepper, leguminous trees are generally used. Where pepper production has been introduced by oriental immigrants as in Malaysia and Brazil, more intensive, unshaded production has predominated resulting in higher yields, but also rapid soil degradation in Malaysia (Purseglove 1968).

When confronted with such evidence, the average agronomist would conclude that leguminous trees have been chosen for their nitrogen fixing ability. It would probably be wrong however to conclude that this was the only, if indeed the major, consideration used in choosing these trees by ancient farmers in widely separated parts of the globe.

Certainly, these farmers could not have been aware of the nitrogen-fixing ability of these trees since even now, evidence for such fixation is poorly documented and mostly based on circumstantial evidence (Nair 1982, Orchard & Darb 1956, Salinas & Sanchez 1971, Pak et al. 1977, Felker 1978, Radwanski & Wickens 1969, Enriquez 1983), the exception being actual measurement of acetylene reduction by *Inga jinicuil* in association with coffee (Roskoski 1982). Leguminous trees were probably an important constuent of the forest in which cocoa, coffee, cinnamon, and tea occur naturally. In selective cutting of these forests, statistical considerations might account for a large proportion of leguminous trees being left for shade even if no selection were made. Another argument against nitrogen-fixation as a criterion for selection of leguminous trees for shade is the low nitrogen requirements of crops such as coffee, cocoa, tea (Sanchez 1976) and cinnamon, especially when grown under shade (Willey 1975). Furthermore,coffee and tea were domesticated and associated with leguminous trees at high elevations in the tropics where soils of volcanic origin often have high organic matter contents and nitrogen is unlikely to be a limiting element. Even at lower elevations in the tropics, soils of volcanic origins show considerable N-supplying power (Kass et al. 1983).

Evidence for benefits of leguminous as opposed to non-leguminous trees for shade of cocoa was obtained by Enriquez (1983) in Costa Rica (Table 1). It is impossible to tell, of course, whether the increase is due to nitrogen supplied by the leguminous trees or due to one of the other factors enumerated above.

Roskoski (1981-1982) has estimated nitrogen fixation rates of 35-40 kg^{-1} $^{-1}/yr^{-1}$ by *Inga jinicuil* Schelechter as measured by acetylene reduction when used as a coffee shade in Mexico. No evidence for nitrogen fixation was found in *Inga vera* although this species is known to nodulate (Ollen & Alle 1981). Coffee yields associated with *Inga jinicuil* were 37% higher than those associated with *I. vera*. This study also pointed out that not all leguminous trees bear nodules and fix nitrogen.

There are six reasons, other than nitrogen fixation,for which legumes might be favored for use as shade trees in perennial crops:

1. Production of valuable products.

2. Abundant litter production (which might be related to N_2 fixation).

TABLE 1. Production and pod index of Cocoa in four years with shade of *Cordia alliodora* and *Erythrina poeppigiana* (means of three varieties of cocoa).

System	Year	Cocoa yield (kg/ha^{-1})	Pod index (pods per kg of dry cocoa)
Cocoa + *Cordia*	1979	83.25	18.2
	1980	468.73	23.4
	1981	371.50	24.5
	1982	708.36	25.0
	Mean	407.96	22.8
Cocoa + *Erythrina*	1979	162.75	20.5
	1980	631.70	20.9
	1981	979.11	18.1
	1982	924.43	32.1
	Mean	674.50	20.7

From Enriquez 1983.

3. Ease of husbandry. Most leguminous trees reproduce readily from stakes or large cuttings.

4. Good coppicing ability; while this might be related to nitrogen fixation, it is belied by the fact that several non-legumes also coppice well.

5. A canopy structute that permits a desirable type of shade.

6. Drought resistance: non-competitive root structure.

The leguminous genera commonly used for shade do not produce any particularly valuable products. Neither *Albizia, Erythrina, Gliricidia,* or *Inga* are prized for their timber. All of these species, with the exception of *Erythrina,* can be used for fuelwood however (National Academy of Sciences 1980) and *Erythrina* and *Inga* produce edible products. *Inga* pod pulp, *Erythrina* flowers, and wood from *Gliricidia* and *Albizia* might have been more important to the people who first used these trees for shade than they appear today to an economist.

While litter production under leguminous trees used for shade is considerable, not too much data are available for comparison of leguminous and non-leguminous trees. Russo (1983) obtained 4,200 $kg/ha^{-1}/yr^{-1}$ dry matter in leaf fall with *Erythrina poeppigiana* which had been pollarded at the beginning of the measurement period. Hadfield (1963), quoted by Willey (1975), gives a figure of 5,000 $kg/ha^{-1}/yr^{-1}$ for tea shades which are presumably legumes; for, with the exception of *Grevillea robusta* A. Cunn., use of non-legumes as tea shades is rare (Purseglove 1968). However, the trees measured by Hadfield were probably not pollarded annually. As can be seen in Table 2, pollarding reduces considerably the biomass returned in form of leaf litter. Nye (1961) and Greenland & Kowal (1960) give somewhat higher figures (10,000 to 12,500 $kg/ha^{-1}/yr^{-1}$) for tropical rainforest but they were probably dealing with a higher density of larger trees than would be found in a coffee or tea plantation. A comparison of litter production by *Cordia* and *Erythrina* was made in the experiment of Enriquez (1983) and is shown in Table 3. As we shall soon see that coppicing ability is an almost universal attribute of leguminous trees, figures for litter production may be more than quadrupled if the biomass of material pruned annually is included (Russo 1983) (Table 2).

The four genera we have mentioned as the most common coffee, cocoa, and tea shades are all fast growing and easy to reproduce (National Academy of Sciences 1979, 1980).

Use of large stakes (over 2 m in length) of *Erythrina* and *Gliricidia* permits rapid establishment of the trees and minimal competition with the associated species. It has been noted in Turrialba, Costa Rica,that a stake of *Erythrina poeppigiana* 2.5 m long and 8-10 cm in diameter, readily obtained from a two year old branch, can attain, six months after planting, a height of 4-5 m and a crown consisting of 15 branches with a total diameter of 3-4 m. Further measurements of such growht of leguminous and non-leguminous species are presently being carried out in Central America (Otarola & Ugalde 1983).

A fairly good argument can probably be made for coppicing ability as a desirable characteristic that leguminous trees commonly used as shade trees share, in fact, there would appear to be very few legumes that do not coppice well (National Academy of Sciences 1980). There are several non-legumes, such as Eucalyptus, which do coppice well, but good coppicing ability would seem to be much more common among the legumes.

This brings us to another attribute of the leguminous trees which might not be related to nitrogen fixation: the provision of a desirable type of shade. The light shade provided by *Gleditsia* (National

TABLE 2. Annual dry matter and mineral contents of prunings and litter fall of *Erythrina poeppigiana* trees (280/ha) interplanted with coffee, pruned once and twice yearly (kg/ha).

Component	Pruned biomass		Fallen leaves		Total biomass deposited on the ground	
	1 pruning	2 prunings	1 pruning	2 prunings	1 pruning	2 prunings
Dry matter	18.474	11.839	4.280	1.914	22.754	13.753
Nitrogen	237.3	227.6	93.3	41.7	330.6	269.3
Phosphorus	26.0	18.0	6.4	2.9	32.4	20.9
Potassium	130.0	139.0	25.7	11.5	155.7	150.5
Calcium	224.8	84.0	94.2	42.1	319.0	126.1
Magnesium	56.0	38.0	30.0	13.4	86.0	51.4

Source: Russo 1983.

TABLE 3. Total dry matter and nutrient content in litter* fall of cocoa associated either with *Cordia* and *Erythrina* (kg/ha^{-1}).

	Cocoa under *Cordia*		Cocoa under *Erythrina*	
	Cocoa	*Cordia*	Cocoa	*Erythrina*
Dry matter	3.000	2.938	3.959	2.475
N	34.4	60.2	53.4	62.4
P	3.0	7.8	2.8	3.5
K	24.2	33.1	27.0	13.0
Ca	49.6	58.5	68.9	47.1
Mg	20.3	23.1	28.1	12.4

* Includes leaves and branches
From Alpizar et al. 1983.

TABLE 4. Light interception by varying populations of different species in four different directions from trees (10 observations per direction) (Daccarett 1967).

Species	Population trees/ha^{-1}	Light interception, 2.5 m from tree (%)				
		north	east	south	west	mean
Erythrina poeppigiana	24	53.83	49.82	56.21	62.57	55.60
Pithecellobium saman	20	9.02	10.37	27.36	28.47	18.80
Gliricidia sepium	24	24.63	25.73	32.56	54.90	34.44
Cordia alliodora	8	0.95	1.14	2.86	13.36	6.08

Academy of Sciences 1979), *Gliricidia* (National Academy of Sciences 1980) and the non-leguminous *Grevillea* (National Academy of Sciences 1980) is often mentioned, but the authors were unable to find any data with the exception of an M.S. thesis by Daccarett (1967) who measured light interception by three leguminous species and *Cordia alliodora*. Unfortunately, populations of the trees in the study varied so that the data are only comparable for *Erythrina poeppigiana* and *Gliricidia sepium*, two legumes, which do however have differing types of crowns. No evaluation of light quality was made. The data, however, are given in Table 4 as similar data are not readily available.

Pinute and multipinute leaves so common in leguminous trees might produce a more favorable type of shade although there seems to be no experimental verification of this possibility. Norman et al. (1971) compared gap-size and light intensity distribution below canopies of sunflower (*Helianthus annuus* L.) which has simple leaves and sumac (*Rhus typlina* L.) which has compound leaves. A type of canopy permitting good light penetration has been cited as a positive attribute of species such as *Leucaena* (Brewbaker & Hutton 1979) and *Gliricidia sepium* (National Academy of Sciences 1980), but no quantitative data are presented. It would seem to be an area meriting further research.

Rooting habit of leguminous trees is another area of much speculation and little factual data. Again, *Leucaena* is supposed to have a deep taproot and few lateral roots, thus favoring its use in alley cropping schenes (Dijkman 1950, Blom 1980). Kang et al. (1981) indeed showed that *Leucaena* root mass drops off considerably betwenn 20 and 75 cm from a hedge row but no comparative data for other species were presented. Daccaret (1967) found more roots of *Erythrina poeppigiana* and *Gliricidia sepium* than of *Pithecellobium saman* and of the non-leguminous *Cordia alliodora* at a distance of 1 m from the respective trees in a tree-pasture association. The pasture species had a larger proportion of their roots in the upper 20 cm under *Erythrina* than under any of the other species or in the control. It would appear that there might be intra - as well as inter-family differences with regard to rooting habit among shade species.

In conclusion, it would appear that there is some evidence that nitrogen-fixing ability might not be the only attribute of leguminous trees which has favored their use for shade. There is, however, hardly enough data to draw many conclusions about these attributes because even nitrogen fixation has not been demonstrated in many leguminous species used for shade. Some of the characteristics considered here, such as litter production, pruning management and coppicing ability, amount and type of shade, rooting habit, as well as nitrogen fixation would appear to merit a considerable research effort to see if differences do exist, not only for legumes as a group but also among different leguminous species.

b. Shade for animal and/or pasture species

The practice of letting seedlings from natural forest regeneration thrive in pastures is well known in Costa Rica and other regions (Budowski 1918a, Lagemann & Heuveldop 1983). The benefits of shade trees in pasture are considerable; and according to Budowski (1982), it is necessary to consider both biological and sociological aspects to evaluate advantages and disadvantages of silvopastoril associations. The main biological aspects are:

- A better utilization of the vertical space is achieved and to a certain extent, natural ecological models are simulated in regard to form and structure of vegetation.
- There is greater resistance against adverse rainfall conditions (both water excess and deficiency).
- Temperature extremes are mitigated at ground level.
- A large amount of biomass returns to the soil as organic matter through fallen leaves, fruits, flowers and branches.
- Tree roots can reduce compaction and improve infiltration.

The above advantages would apply to both leguminous and non-leguminous species. With leguminous trees, there should be additional advantages such as higher nitrogen content of the litter and foliage which can be used as feed of browse (Blom 1980, Felker & Bandurski 1979). Table 5 shows the nutritive value of the foliage of four leguminous tree species as compared with other forage legumes and grasses commonly used in the humid tropics.

As shade species, leguminous trees have sometimes been reported to have a favorable effect on the grass growth beneath them. According to Daccarett & Blydenstein (1968), the protein content of grasses growing beneath *Erythrina poeppigiana* was higher than that of grasses growing beneath non-leguminous trees. Currently, at the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) in Turrialba, Costa Rica, evaluations of production of *Pennisetum purpureum* associated with *Erythrina poeppigiana*,

TABLE 5. Nutritive values of four legume trees, compared with other forages, legumes and grasses.

	C.P. (%)	D.M. (%)	IVDDM (%)	M.E. (Mcal/kg D.M.)
Erythrina poeppigiana	23.2 - 34.4	23.4 - 24.1	56.6	2.00
E. berteroana	24.3	27.8		1.97
Gliricidia sepium	24.8 - 27.6	23.1 - 35.9		
Leucaena leucocephala	25.2 - 35.6	25.9		
Cajanus cajan	24.2	25.0		
Manihot esculenta-leaves	15.8 - 32.1	27.9		1.43
Ipomea batatas-leaves	15.3	16.4		
Dolichos lablab	20.2	20.4		2.58
Musa spp. var. pelipita-leaves	13.5	22.2		1.58
Panicum maximum	10.7	19.5	54.1	1.95
Pennisetum purpureum	10.9	16.7		1.98

C.P. = Crude protein (%); D.M. = Dry matter %; IVDDM = In vitio digestibility of dry matter; M.E. = Metabolisable energy (Mcal/kg D.M.).

Sources: Benavides 1983b, Franco 1983, Moreno 1982, Roldan Perez 1981, Russo 1983.

Cordia alliodora, or no tree species are being compared (Bronstein 1983). Some preliminary results are shown in Table 6. Finally, Table 7 summarizes several leguminous trees commonly found in pasture in Costa Rica and some of their uses.

Mention should also be made of *Alnus acuminata*, a nitrogen-fixing non-legume commonly found in pastures at the higher elevations in Costa Rica (Beer 1980). Effects of the trees on pasture production have not been measured, but the frequency with which the association is encountered should imply some benefit.

c. Associations with annual crops

Associations of woody legumes with annual crops do not appear to be very common in traditional agricultural systems, the exceptions being leguminous trees in association with various annual crops in the Sahelian zone of Africa (Nair 1982) and the use of living stakes of *Gliricidia sepium* as a support for *Dioscorea* yams in the forest zone of West Africa. Felker (1978) reported increased millet and peanut yields near *Acacia albida* Del., trees in Senegal while increased wheat yields near the same species were reported from the Sudan (Radwanski & Wickens 1969). Charreau & Vidal (1965) reported higher levels of soil nitrogen, organic matter, Ca, Mg, K, Na and available P_2O_5 close to *Acacia albida* trees in Senegal than in soil outside the tree canopy.

While most of the associations of leguminous trees and annual crops occur in the semi-arid tropics, with the exception of the *Gliricidia*-yam association, most efforts at improving the system have been centered in the humid tropics (Steiner 1982, Kang et al. 1981). The bulk of the research effort with alley cropping has been at the International Institute for Tropical Agriculture, in the forest zone of Nigeria (International Institute for Tropical Agriculture 1982, 1981), utilizing *Leucaena leucocephala* Lam., *Tephrosia candida* (Roxb) DC, *Cajanus cajan* (L.) Millsp., and *Gliricidia sepium* (Jacq.) Steud. Recently a program has begun at CATIE in Turrialba, Costa Rica, using *Gliricidia sepium* and *Erythrina poeppigiana*

TABLE 6. Grass biomass production (kg/ha) with and without shade of *Erythrina poeppigiana* trees*.

	With trees	Without trees
Cynodon plectostachyus[1]	5,786 kg/ha/six months**	2.126 kg/ha/six months
Pennisetum purpureum[2]	6,390 kg/ha/four months***	5,690 kg/ha/four months

[1] Unpublished data, Bronstein 1983. Personal communication.

[2] Unpublished data, Benavides 1983a. Personal communication.

* Both without fertilizer.

** Trees planted 6 m x 6 m.

*** One-year old trees planted 3 m x 2 m and 3 m x 1 m.

TABLE 7. Legume trees in pastures in Costa Rica.

	Shade	Human food	Living fence	Fire wood	Wood	Forage
Erythrina poeppigiana	x		x			x
Erythrina fusca	x					x
Schizolobium parahybum	x					
Inga spp.	x	x		x		x
Pithecellobium saman	x			x		x
Enterolobium cyclocarpum	x			x		x
Gliricidia sepium	x	x	x	x		x
Diphysa robinioides	x		x	x		
Hymenaea courbaril	x	x		x		x
Cassia grandis	x	x				x
Pithecellobium dulce	x		x	x		x
Lonchocarpus spp.	x			x		
Albizia adinocephala	x			x		
Andira inermis	x			x		
Caesalpinia eriostachys	x			x		
Platymicium pinnatum	x			x		
Pterocarpus hayesii	x			x		

(Walpers) O.F. Cook as alley crops (Kass et al. 1983). Although Steiner (1982) saw little prospect for alley cropping in the humid tropics due to the higher cloud cover, exacerbating effects of shading, efforts in the drier areas have often come up against problems of competition for water and slow growth of the leguminous species under these conditions (International Institute for Tropical Agriculture 1981).

At CATIE, we have found that in the first year of alley crop establishment, total dry matter production of a maize-cassava-bean cropping system was increased by the introduction of both *Erythrina* and *Gliricidia* alley crops. Nitrogen recovery of the entire system was increased by 73 and 34 $kg/ha^{-1}/yr^{-1}$ by the introduction of *Erythrina* and *Gliricidia* respectively as alley crops.

Another situation where legumes may be used for shade for both annuals and perennials is the home garden. Species found in such gardens in Costa Rica, Haiti, the Philippines and Singapore have been ennumerated by Price (1982). While there is no quantitative data on the relative importance of the different species, very few of the trees reported by Price were legumes. Of 38 species of trees found in Costa Rica home gardens, only three were leguminous. Of 17 tree species in a Haitian gardens, five were legumes. Of 52 trees species in the Singapore gardens, only eight were legumes. In situations where many fruit trees are grown, and where there is considerable input of organic matter from household trash, leguminous trees may not offer too many benefits. It should be remembered, however, that numbers of plants of each species were not reported.

d. Living fenceposts and other non-associative uses

Use of living trees and hedges as fences is a common practice in the tropics (Bond 1944, Sauer 1979, Baggio 1982). Plants are most frequently established from cuttings and can subsequently be pruned back to produce more cuttings, fuelwood, green manure, or fodder for animals in the case of nontoxic species. The comparative advantages and disadvantages of this practice have been summarized by Budowski (1981a). Surveys of the practice in Costa Rica (Sauer 1979, Baggio 1982, Lagemann & Heuveldop 1983) and Nigeria (Bond 1944) have shown that considerable management skill exists among local farmers which contributes considerably to their success with the practice. Researchers attempting to emulate local practices have often had less success in the establishment of such living fences than traditional farmers.

The existing data cannot give a clear indication of whether leguminous trees are favored for living fence posts, but coppicing ability, rapid growth, and ease of husbandry discussed earlier would certainly be of importance in determining the suitability of a particular species for living fences. In the National Academy of Sciences survey of firewood species (National Academy of Sciences 1980), where rapid production of biomass suitable for fuel is the major criterion for recommendation, 32 of the 62 recommended species are legumes while another five are of the genera *Alnus* and *Casuarina*, for which nitrogen fixation has been demonstrated. In Costa Rica, where only eight of the 55 species mentioned by Sauer as fencepost species are legumes, of the three most commonly used genera (*Erythrina*, *Gliricidia* and *Bursera*), the first two are legumes (Sauer 1979).

An attribute of many legumes which was of more value before the introduction of barbed wire which favored their use as living fences was thorniness (Sauer 1979). *Acacia albida* (Bond 1944) and *Pithecellobium dulce* (National Academy of Sciences 1980), have been cited as valuable for keeping cattle out of undesirable places.

In the provision of shade as an amenity, leguminous trees are often favored in the tropics. In addition to the type of shade and ease of management mentioned earlier, the showy flowers and value as a bee forage for honey production are prized in genera such as *Calliandra*, *Erythrina*, *Gliricidia* and *Inga* (National Academy of Sciences 1980).

CONCLUSIONS

In the present paper, we have reviewed the use of leguminous trees for shade in four different contexts: with perennial crops, in pastures, with annual crops, and in living fence posts and other non-associative uses. We have noted a tendency for leguminous trees to be favored over non-leguminous trees in all these contexts although the use of non-legumes for these purposes is often quite widespread. Emphasis was placed on whether legumes offer any particular benefits over non-legumes as shade trees, which would justify their widespread use and a research effort to increase their use as shade trees. In general, it was found that while leguminous trees have many attributes which favor their use as shade trees, many of these attributes are not exclusive to the legumes. There are non-leguminous trees, which are easy to establish, coppice readily, produce a desirable type of shade, have showy flowers, and produce abundant litter. Even nitrogen fixation, the factor often cited as a reason for favoring legumes, can be found in non-leguminous genera such as *Alnus* and *Casuarina,* which are prized as shade trees (National Academy of Sciences 1980).

The literature was searched with special reference to situations where leguminous and non-leguminous shade species were compared as to their effects on the shaded species and/or the environment. Very few such comparisons have been documented although there are certainly more such comparative studies which have either not been published or published where the authors were unable to consult them. Results of one study with perennial crops (Enriquez 1983) and two studies with pasture species (Daccarrett 1967, Benavides 1983a) are given. All of these studies show benefits from using leguminous as opposed to non-leguminous shade species.

There is obviously a great scope for a larger use of leguminous trees for shade. Foremost among the reasons is the need for reforestation with trees that restore soil fertility while binding the soil with their roots and allowing better water infiltration (Blom 1980). The greatest need is for reforestation of marginal lands that have been degraded and compacted and are presently being eroded (National Academy of Sciences 1980). The use of large stakes or cuttings offers a means of producing a crown in relatively little time; and it has been suggested that trees like *Gliricidia* could readily be used to eradicate persistent grasses like *Imperata* by shading them out (Franco 1983).

THE FUTURE OF LEGUMINOUS SHADE TREES

There is obviously a great scope for a larger use of legumes. But perhaps the greatest scope of legume trees resides in the use in agroforestry systems involving associations with grasses for pasture or animal or perennial crops that benefit from such associations by taking advantage of the litter, the better microenvironmental and soil improvement. The fact that many uses can be derived from the large number of leguminous trees to benefit human needs directly or indirectly provides unequalled opportunities for research.

Perhaps the greatest need at this time is information and transfer of knowledge.

The following example of a little known legume tree *Calliandra calothyrsus,* taken from a forth--coming book of the National Academy of Sciences (1983), illustrates the case:

"In 1936, foresters transported seed of this small Central American tree from Guatemala to Indonesia. They were intrested in *Calliandra* and other legumes as possible green manures of shade trees in coffee plantations. In particular, they wanted an alternative to *Leucaena,* notably for use at high altitudes where *Leucaena* did not perform well. The foresters planted test plots of *Calliandra* in a few places in East Java, but World War II and the subsequent fighting in Indonesia interrupted the investigations, and for 20 years the plant remained largely forgotten by science.

Then, in the 1960s, administrators of Perum Perhutani, the government forest corporation of Java, noted that villagers in East Java had spontaneously adopted *Calliandra* and were cultivating it for their firewood needs. The villagers were so successful that in 1974 Perum Perhutani began encouraging the widespread testing and planting of *Calliandra*. By 1981 the steadily expanding plantations, many planted by villagers themselves, covered almost 2,000 km^2 on Java. Today Javanese cultivate *Calliandra* widely, often intercropping it with fruit trees and vegetables. The tree has become so popular in rural areas that "Kaliandra" is now a widely used name for children.

However, *Calliandra* remains essentially unknown elsewhere, and the purpose of this report is to recount Java's experience in the hope that other countries will be encouraged to investigate *Calliandra's* promise for themselves".

The report shows that *Calliandra* fixes nitrogen, is an excellent fuelwood, improves the soil, provides good shade, covering the soil to prevent runoff and erosion. It also produces a forage with 22% protein that can be dried, pelleted, and exported. The flowers produce high quality honey. There are probably dozens of leguminous trees with a future (and probably several dozens with a past) similar to *Calliandra*.

In Costa Rica, we tested *Calliandra* for coffee shade, together with *Acacia angustissima* and the Brazilian "bracatinga" (*Mimosa scabrella*). All these species were readily accepted by the coffee farmers in the San Ramón area. They asked for more seedlings, and our small nursery was not large enough to supply the demand. The irony is that *Calliandra* had to travel to Indonesia to get recognition in its native Costa Rica.

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