Nitrogen fixation by forage legumes in sub-Saharan Africa: Potential and limitations*

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Summary

AVERAGE CROP *yields throughout sub-Saharan Africa are amongst the lowest in the world. Even the development and widespread use of improved crop cultivars has had little impact as soil nutrient deficiencies impose severe limits on plant production.*

Of the many possible nutrient deficiencies, lack of N imposes the most widespread and strongest restrictions on plant and animal production. It is also an expensive element to replace and chemical fertilizer N has virtually no role in African subsistence cropping systems.

The well known alternative to fertilizer N is the N fixed by legumes. Yet even with this ostensibly simple and cheap approach, many environmental, nutritional, biological and economic factors restrict the N fixing potential of the legume–Rhizobium association.

This paper surveys the many limits on legume N fixation encountered in sub-Saharan countries and discusses the various production systems in which legumes make an important contribution. It finally highlights research deficiencies that need to be corrected if legumes are to be effectively integrated into both crop and animal production systems.

Introduction

The per caput food production in sub-Saharan Africa declined by about 20% over the past two decades (Cummings, 1976). If similar production trends continue throughout the 1980s, meeting the minimum energy consumption levels of the population will require an additional 18.5 million tonnes of grain per year by 1990 (USDA, 1981).

Nobel laureate Borlaug recently said: "Without doubt, the single most important factor limiting crop yield on a worldwide basis is soil infertility. Lack of one or more essential nutrients is usually the joint effect of weathering followed by leaching and erosion combined with extractive farming practices" (Borlaug, 1982). In Africa such deficiencies are obviously important since, despite the increased availability of improved cultivars, national crop yields have shown little change (Cummings, 1976).

Nitrogen is one of the major plant nutrients and satisfactory levels of grain and forage crop production depend on an adequate supply (Russell, 1966). While the N status of soils can be improved by the addition of N fertilizer, it is an expensive input and this is reflected in its low consumption in Africa (IFDC, 1980).

A more effective and cheaper way of raising the N status of the soil is to exploit the ability of forage legumes to fix appreciable quantities of atmospheric N (Tables 1 and 2). This N accumulates in the soil and is released over several seasons to non-legume crops if the soil is cultivated, or to companion grasses in pasture land. Thus forage legumes can indirectly boost crop yields and directly resolve quantity and quality problems in African grasslands. In their unimproved state the annual dry matter yields from natural grassland may be as low as 1177 kg/ha and the crude protein content less than the critical value of 6 or 7% for much of the year (Weinmann,1955; Nilson and Milford, 1967; Anon., 1970). Thus severe restrictions are placed on livestock production, particularly during the dry season which can last for as long as 9 months. This paper: (1) reviews the present state of knowledge about the biological contribution of N by forage legumes in sub-Saharan Africa; (2) indicates the main factors limiting the contribution of biological N by forage legumes; (3) highlights the potentials of legume—food crop–livestock interactions in various production systems; and (4) suggests areas where intensified research is justified in terms of scientific knowledge and practical benefits.

Table 1. *Nitrogen fixation rates (kg/ha) by some forage legumes in sub-Saharan Africa*.

Legume	Average	Range	Location	Source
Centrosema pubescens	259	126–395	Nigeria	Moore (1960); Odu et al (1971); Adegboola and Fayemi (1972)
Centrosema pubescens	280	–	Nigeria	Moore (1962)
Centrosema and Stylo-	84		Uganda	Horrell and
santhes guianensis	161			Newhouse (1966)
Desmodium uncinatum	178	–	Kenya	Anon. (1969)
Glycine javanica	73 (first 5 years)	–	Kenya	Jones (1942)
(G. wightii)	45 (last 4 years)	–	Kenya	Jones (1942)
Lucerne	56 (120 days)	–	Kenya	de Souza (1969)
Leucaena	110	–	Tanzania	Hogberg and Kwarnstorm (1982)
Leucaena	287 (6 months)	225–350	Nigeria	Sanginga et al (1984)
Lotonosis bainesii	62	–	Zimbabwe	Clatworthy (1970)
Stylosanthes spp.	124	34–220	Nigeria	Odu et al (1971)
S.guianensis	290	–	Uganda	Wendt (1970)
S. guianensis and Desmodium intortum	94	–	Malawi	Anon. (1961)
Trifolium repens (cv Louisiana)	–	224–336	Kenya	Morrison (1966a)
T. semipilosum	80	–	Zimbabwe	Clatworthy (1970)

Table 2. *Nitrogen fixation by trees.*

Species	Method of estimation	N fixed (kg/ha/year)
Acacia mearnsii	B	200
Acacia holosericea	A	6

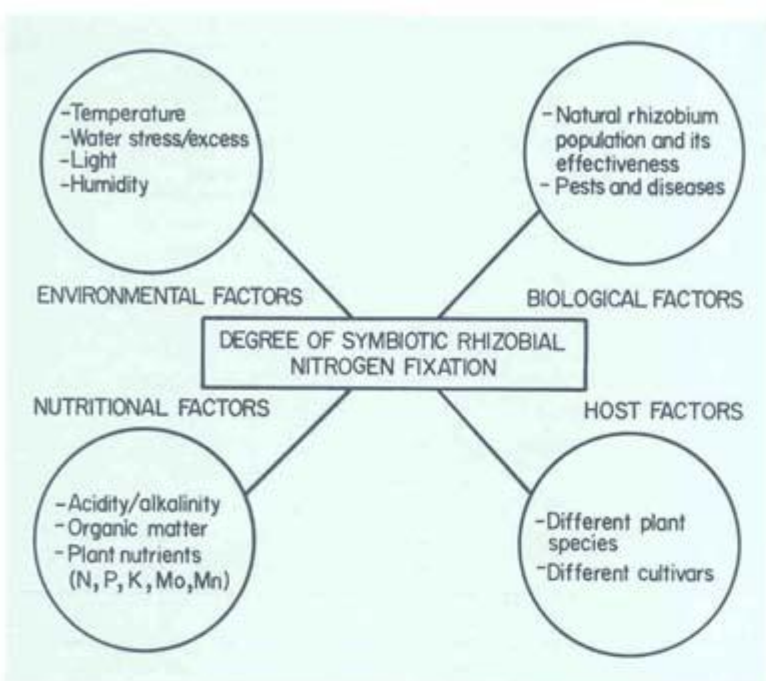
Acacia pennatula	A	34
Gliricidia sepium	A	13
Inga jinicuil	A	35
Leucaena leucocephala	C	500–600
	A	110
Casuarina equisetifolia	B	58
	D	>260
	I	46[a]
Allocasuarina littoralis	B	218

A: acetylene reduction assay; B: nitrogen balance studies; C: total N accumulation in the forage fraction;
D: difference method; I: isotopic method (A value).
[a] 11-month-old trees; 10 000 trees/ha.
Source: Duhoux and Dommergues (1984).

The potential and limits to symbiotic nitrogen fixation

The potential symbiotic N fixation by a given legume is defined as the maximum activity of that legume when nodulated with the most effective rhizobium strain and grown under the most favourable environmental conditions (Gibson et al, 1982). Thomas (1974), Keya (1977) and Ayanaba (1980) concluded that tropical forage legumes in Africa have, under good management, a potential similar to that recorded in Australia and in temperate regions. However, in practice there are four major factors which limit the quantities of N fixed by rhizobia (Figure 1).

Figure 1. *The four major influences on nitrogen fixation.*



Environmental

The effects of environmental factors on nodulation and N fixation in legumes have been extensively reviewed by Gibson et al (1982). Results relating to forage legumes in sub-Saharan Africa are limited, but the salient points are discussed in the following subsections.

Temperature

For different species the processes of infection, nodule development, and N fixation usually have different maximum and minimum temperatures. For example, nodule formation on *Trifolium subterraneum* occurs at a temperature as low as 7°C whereas for the majority of tropical and subtropical legumes 15–18°C is a more common minimum. At the upper end of the temperature range, the maximum (30–40°C) for the tropical species is higher than that for the temperate ones (Souto and Dobereiner, 1970; Gibson, 1971).

Mayer and Anderson (1959) demonstrated that a temperature of 30°C inhibited symbiotic N fixation in the temperate species *T. subterraneum* (cv Bacchus Marsh) and concluded that similar temperatures might limit N production by legumes in tropical regions. However, Small and Joffe (1968) compared the effects of various temperatures (12°C, 19°C, 26°C, 33°C, 40°C and 45°C) on clovers of European origin (*T. repens* and *T*. *pratense)* and African cultivars of *T*. *africanum* and found that the European species were more sensitive to high temperatures than *T*. *africanum.*

In Sudan, Habish (1970) found that species of *Acacia* can grow and nodulate effectively at 35°C, the highest temperature at which nodulation has so far been recorded. High-temperature tolerant strains of rhizobium species from cowpeas which are able to form effective nodules at high temperatures have also been recently isolated (Eaglesham et al, 1981).

High temperatures severely reduce the longevity of commercial rhizobial inoculants, and for this reason refrigeration is recommended during transportation and storage. A lack of adequate refrigeration facilities in many sub-Saharan countries create severe problems in maintaining viable rhizobia in such inoculants.

Water stress/excess

Both water stress and excess can have adverse effects on nodulation and N fixation, and are considered one of the most neglected areas of study on legume–rhizobium association (Gibson, 1977; Gibson et al, 1982). Nodulation, growth and N content of plants were significantly higher at soil moisture contents ranging from 15.0 to 22.5% when compared to the N-fertilized control. At 7.5% soil moisture nodules were confined to the upper part of the root system. The concentration of the nodules towards the surface was attributed to the higher moisture content of the upper layer (Habish, 1970). Soil moisture deficits are frequently associated with high soil temperatures; therefore, the distinction between effects due to moisture stress and temperature is difficult to make in the field.

Kanyama Phiri (1984) reported that shoot, root and nodule dry weights and nodule number of greenleaf *Desmodium* and *Centrosema* were significantly reduced at the lowest moisture regime (10%). Moisture regimes above 35% also tended to reduce the dry weight and nodulation of these two species. Optimum responses were recorded at moisture regimes between 30 and 35%. At the other extreme, waterlogging and poor soil structure produce low oxygen levels in soils. Under both conditions poor nodulation has been reported (Gibson, 1977).

Permanently or temporarily waterlogged soils are common in the highlands and tropical areas of Africa. Since legumes tolerant to waterlogging are known, adaptation to waterlogging is possible. For example *Sesbania rostrata,* which forms stem nodules, has five to ten times more nodules than the best nodulated crops, and has outstanding potential for N fixation in flooded soils (Dreyfus and Dommergues, 1981). In the Ethiopian highlands, the top-yielding African clovers grow best on seasonally waterlogged soils. However, their adaptive mechanisms for effective nodulation and N fixation under such conditions are not known.

Light and air humidity

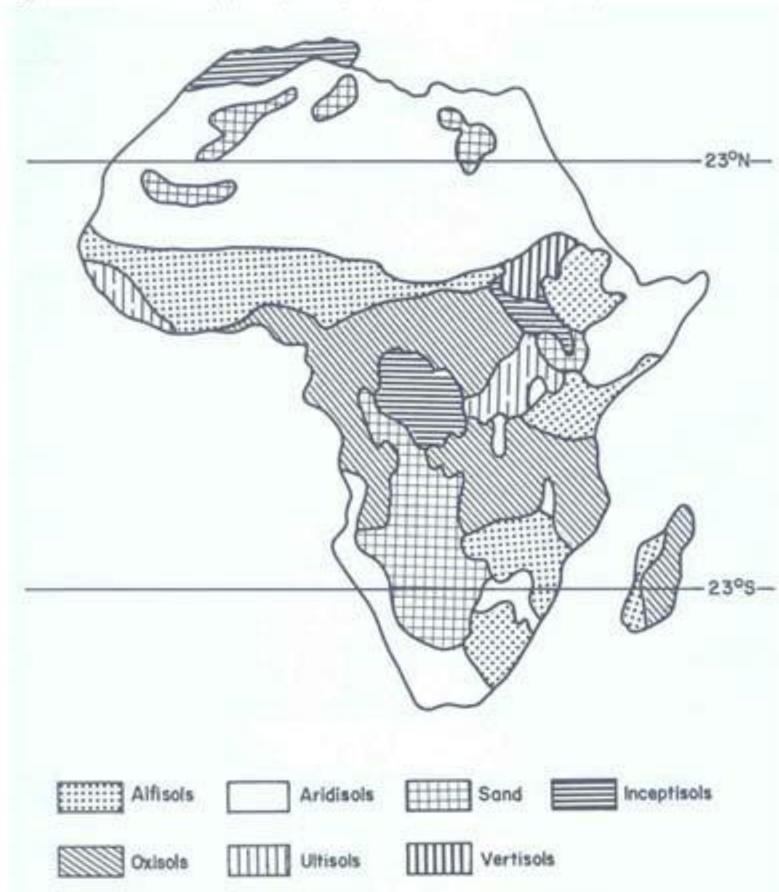
Both photoperiod and light intensity have been reported to affect nodulation and N fixation (Gibson, 1977). The effects of light on N fixation seem to be associated with variations in host plant photosynthesis. Under shaded conditions, i.e. when forage legumes are intercropped or in a mixed pasture, plant growth, nodulation and N fixation are reduced, although in some tropical mixtures this may not always be so. Relative air humidity also limits N fixation at certain periods of the day (Ayanaba and Lawson, 1977).

Nutrition

Nutritional deficiencies and excesses may affect N fixation in legumes directly through adverse effects on root infection, nodule development and nodule function, and indirectly through effects on host plant growth. The limitations imposed by inadequate nutrient supply in the soils of tropical Africa were recently highlighted by Le Mare (1984).

Figure 2 shows the distribution of soil orders in Africa with their major problems and the likelihood of occurrence in these soils. Due to the high prices of commercial fertilizer, plant nutrient deficiencies in the soil cannot be corrected in most agricultural production systems in Africa. Current research at ILCA is therefore aimed at finding plant germplasm which will grow well under low soil fertility conditions.

Figure 2. *The distribution of the major soil groups in Africa and some of their problems*.



Soil order	Problems and their likelihood of occurrence[a]					
	Water	Strength	Erosion	Salt	Acid	Nutrients
Oxisols	**	0	*	0	***	***P,S,Mo,K,Zn
Ultisols	*	0	***	0	***	***P,S,Mo,K,Zn
Alfisols	**	**	***	0	**	**P S,Zn,K
Vertisols	*	***	0	*	0	*P,Zn
Aridisols	***	*	***	***	0	*P,Zn
Inceptisols						
Fine	0	0	*	*	0	0
Sandy	***	0	**	0	*	*P,K,*S*,Zn
Ando(ash)	*	0	*'*	0	*	**P

[a] From 0 (little likelihood) to * * * (very high likelihood).

Phosphorus

Phosphorus is the most important basic ingredient in the successful establishment of forage legumes. Many trials have confirmed this and the yield responses and specific details of these trials are presented in Table 3.

Table 3. *Legume responses to phosphate application.*

Country	Species	kg P/ha	Response (%)	Reference
Ethiopia	Native *Trifolium*	30	600	Kahurananga and Tsehay Asres (1983); Akundabweni (1984); Jutzi and Haque (1984)
Kenya	*T*. subterraneum	24	19	Bumpus (1957)
	T. semipilosum	–	+	Strange (1961)
	Desmodium uncinatum	–	100	Keya et al (1971)
	D. intortum			
	Stylosanthes guianensis			
	T. semipilosum			
Nigeria	*Leucaena leucocephala*	80	–	Sanginga et al (1984)
	S. guianensis	25	45	Haggar (1971)
Uganda	*S. guianensis*	–	+	Horrell and Court (1965)
	T. subterraneum			
	T. repens	67	+	Morrison (1966a)
	T. semipilosum	26	35	Suttie (1970)
	S. gracilis	67	19	Wendt (1970)
	D. intortum	20	82	Wendt (1971)
	D. intortum	197	35	Olsen and Moe (1971)
	Medicago sativa		81	
	S. gracilis		10	

Sulphur and other nutrients

The role of S fertilizer in tropical countries has only recently been reviewed by Kanwar and Mudahar (1983). Possibly because of the widespread use of fertilizers which contain S, such as single superphosphate, little attention has been given to the role of S in N fixation, despite its shortage in the soils of sub-Saharan Africa (Blair, 1979). However, good responses by forage legumes to elemental S and gypsum have been recorded in Uganda (Horrell and Court, 1965; Wendt, 1970), Kenya (Anon., 1969) and Nigeria (Haggar, 1971).

Forage legumes responded positively to K applications as reported by I'Ons (1969) in Swaziland and Wendt (1970) in Uganda.

Micronutrient deficiencies and toxicities are widespread south of the Sahara and deficiencies/responses in various crops and forages have been reported (Kang and Osiname,1972; Haque and Kamara,1976; Cottenie et al, 1981; Sillanpaa, 1982; Haque, 1983; Faye et al, 1983). However, there is little information on the effect of micronutrients on N fixation in forage legumes in sub-Saharan Africa.

Soil acidity and seed pelleting

Large areas of African soils with serious nutrient limitations are essentially acid and tend to become more so under cultivation, especially in heavy rainfall areas and if N fertilizers are used. Acidity can easily be corrected and, as pH rarely needs to be raised beyond 5.5, the amounts of lime needed to do so are generally not large.

However, while temperate legumes like lucerne and subterranean clover do not grow or nodulate well in acid soils (Birch 1959; Morrison, 1966b), some tropical legumes seem to be adapted to acid soils and often suffer from micronutrient imbalances once the pH rises above 5.5. For example in Nigeria, on soils with pH ranging from 4.2 to 4.8, Adegboola (1964) found that lime adversely affected the production of dry matter in *Centroserna pubescens.* On a deep red Koalisol (pH 4.8) in the middle veld of Swaziland where deficiencies of Ca have been recorded, there were indications of a slight depressive effect on the growth of *Desmodium intortum* at high liming rates (I'Ons, 1968). Work in Kenya with *Desmodium urtcinatum* has shown that the reduction in growth following liming was associated with a decrease in the number of nodules (Anon., 1969). Results from South Africa (Small, 1968) demonstrate the difference between tropical and temperate legumes. The local *Trifolium africanum* nodulated and fixed N at a pH of 4.0 when sufficient Ca was available whereas the European species, *Trifolium pratense,* failed to nodulate. Odu et al (1971) in studies on Nigerian soils found that *S. guianensis* and *C. pubescens* nodulated effectively and grew best under acid conditions. At a pH of 8.0 nodulation was often completely inhibited. However on some soils, heavy applications of lime (up to 10 t/ha) have had no effect on legume growth and nodulation (Olsen and Moe, 1971) but the reasons for this are unclear.

Because of concern about poor nodulation in acid soils, seed pelleting techniques were developed in Australia to protect the rhizobia and aid nodulation of temperate legumes (Loneragen et al, 1955). The role of lime pelleting in the tropics has been seriously questioned by Norris (1967) on the grounds that tropical legumes are "naturally adapted to acid soils, efficient at obtaining Ca for nodulation and possess acid-tolerant (alkali-producing) rhizobium". He further pointed out that there is little published evidence to support lime pelleting for these species.

However, seed pelleting has proved promising for the temperate legume *Trifolium subterraneum* in high-altitude areas of Kenya where soils are acidic, with pH values ranging from 4.7 to 5.5 (Morrison, 1966b). Yet at Kitale, various pelleting materials were tested for *Desmodium uncinatum* and the results showed that the dry matter yields of plants grown from inoculated seed which was pelleted with rock phosphate, gypsum or lime did not differ significantly from those of the control plants (Anon., 1969). There is obviously a need for more studies on the value of pelleting forage legume seeds.

Salinity

High salt levels are a major limit to growth in many soils of the arid and semi-arid zones. Given the recent advances in the use of tissue culture for selection of salt-tolerant plants, it is likely that this major obstacle will be overcome by the use of these techniques.

Biological

The presence of appropriate rhizobium

The presence or absence of the appropriate rhizobium in the soil dictates whether inoculation of the legume seed is required. Those species or varieties which do not require inoculation have obvious advantages at the farm level. The relationships between rhizobium and tropical forage legumes are reviewed by Date and Halliday (1980).

There has been some controversy over the need to inoculate tropical legumes. On the one hand, Norris (1966) states: "As a broad generalisation it can be said that many tropical legumes will nodulate successfully without inoculation", and there is evidence from African sources to support this statement. Uninoculated stands of *Pueraria phaseoloides, Centrosema pubescens, Indigofera hirsuta, Aeschynomene americana, Desmodium discolor, Stylosanthes humilis* and *S. guianensis* have all been observed to nodulate vigorously in nursery plots in Malawi. Under the same conditions nodules were also present on *Glycine wightii, Desmodium intortum, D. uncinatum* and *Calopogonium mucunoides* (Anon., 1954). Working with *Alysicarpus glumeceus,* Bumpus (1957) found that the yield from the uninoculated plot surpassed all the inoculated treatments and concluded that none of the commercial strains of bacteria in the 'cowpea group' were as satisfactory as those already present in the soil. In Zimbabwe, *Desmodium discolor* and *D. intortum* have been reported to modulate freely without inoculation (Boultwood, 1964). Similar results and observations have been made in Nigeria (Adegboola, 1964; Oke,1967), Kenya (Anon., 1969; de Souza, 1969; Keya and van Eijnatten,1975), Tanzania (Anon., 1968), and Uganda (Horrell and Court, 1965; Wendt, 1971).

Table 4. *Response of some legumes to inoculation with specific rhizobia*.

Country	Species	Response	Reference
Kenya	Alysicarpus glumeceus	none	Bumpus(1957)
	Desmodium uncinatum	none	Anon. (1969)
	Trifolium labides	positive	Morrison (1963;1964)
	T. semipilosum		
	T. subterraneum		
	T. repens		
Ghana	*Medicago sativa*	positive	Dennis (1977)
Malawi	*Stylosanthes guianensis*	positive	Savory(1972)
Nigeria	*S. guianensis*	positive	Adegboola and Onayinka (1966)
	Leucaena leucocephala	positive	Sanginga et al (1984)

Yet on the other side of the inoculum controversy it is obvious that wide variations exist in the effectiveness of rhizobia isolated from different sites, and some of the indigenous strains may be of limited value to the host legume. In Table 4 details of African trials on the response, if any, to inoculation are presented for a range of legumes. It should also be remembered that rhizobium strains differ in their rates of N fixing, and just because a legume has formed nodules this does not mean that it will not respond to inoculation with a more effective N-fixing strain. In recent studies on modulation in*Leucaena,* Sanginga et al (1984) observed poor establishment of *Leucaena* at two sites in Nigeria, which was due to a combination of poor fertility and ineffective modulation by the few native rhizobia present. Some of these rhizobia were cultured and two isolates formed very effective associations with *Leucaena.* Tree legumes are an important source of browse and make a contribution to the N status of African soils. Some of these tree species have a specific modulation requirement, and details are presented in Table 5.

Table 5. *Tentative classification of native and introduced West African tree legumes according to*

Group	Species	Specificity[a]
Group 1		
Nodulating with fast-growing rhizobia	*Acacia farnesiana*	S
	A. lebbek	S
	A. nilotica	S
	A. raddiana	S
	A. senegal	S
	Leucaena leucocephala	S
	Prosopis juliflora	S
	Sesbania sp.	S
Group 2		
Nodulating with fast- and slow-growing rhizobia	*A. cyanophylla*[b]	–
	A. seyal	S
Group 3		
Nodulating with slow-growing rhizobia	A. albida	P
	A. holosericea	P
	A. sieberiana	S
	Erythrophleum guineense	–
	P. africana	P

[a] S: very specific; P: promiscuous.
[b] This species does not grow in West Africa; it is extensively planted in northern Africa.
– Under study.
Source: Duhoux and Dommergues (1984).

Obviously some tropical forage legumes exhibit rhizobium strain specificity comparable to that commonly associated with the temperate legumes, examples being *Leucaena leucocephala, Lotononis bainesii* and *Stylosanthes guianensis* (cv. Oxley fine stem) (Norris, 1970; Davies and Hutton, 1970). These species form effective nodules only with the aid of inoculation (de Souza, 1969; Thomas, 1972).

There are also a number of indigenous *Trifolium* species in the highlands of Kenya which are extremely specialised and show no cross-inoculation affinities with their temperate counterparts (Bogdan, 1956; Norris, 1956; Norris and t'Mannetje, 1964). De Souza (1969) included one of these species, *Trifolium semipilosum,* in his modulation survey in Kenya. Although this species will nodulate naturall in areas where it grows wild, the use of an effective inoculant is still recommended.

The legume – inoculation argument cannot be seen as a simple choice between black and white. While some generalisations about the need for inoculation appear to be valid, whenever a legume seems to be performing below its potential, the effectiveness of the rhizobia, whether indigenous or in commercial inoculum, should be questioned.

Pests and diseases

Insect pests and plant pathogens have no direct effect on symbiotic N fixation, but they can indirectly affect fixation through their effect on the growth and persistence of the host plant (Gibson, 1977)

Host plant factors

Legume species differ in N fixation, utilisation of the incorporated N, and its redistribution into either seeds or vegetative parts. This type of information is important when selecting forage legumes for protein yield and soil fertility improvement. Host determinants in nodulation and N fixation are reviewed by Gibson (1980).

Legume–food crop–livestock interaction

Forage legumes provide high-quality feed for livestock and increase the yield of any following food crops. There is scope for further strengthening of the links between livestock and food crop production through the strategic introduction of forage legumes into mixed agricultural systems.

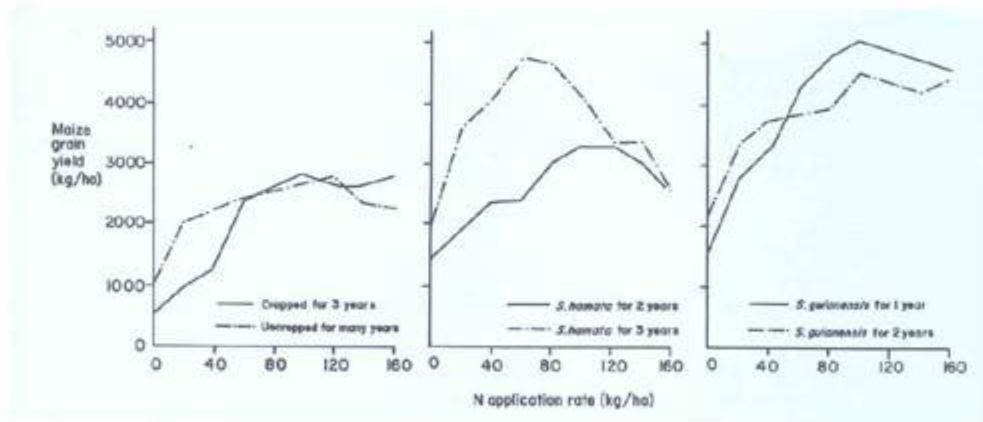
Legume–cereal cropping

The concept of legume ley farming, so important in the integration of wheat and wool production in Australia's mediterranean climate, has been suggested as a promising model for West African savanna zones (Jones and Wild, 1975) but there has been no substantial evaluation of the strategy in sub-Saharan Africa.

The net benefit of legume-derived organic residues to a following non-legume crop depends on the amount of such residues and on their rate of mineralisation. Unfortunately, neither factor is sufficiently well understood. Organic N accumulates over several years under legume-based pastures and subsequent cultivation usually releases from 40 to more than 100 kg N/ha to the first crop and gradually diminishing amounts to succeeding crops (Moore, 1962; Jones et al, 1967; Watson, 1969; Wetselaar et al, 1973).

In northern Nigeria, the N contribution of legumes in fodder banks to the subsequent crop was estimated by comparing the response of maize to N fertilizer. Maize yields after 1 and 2 years of*Stylosanthes guianensis* cv Cook approximated those obtained after 45 and 60 kg of N respectively were applied to an area previously cropped for 3 years with maize. Maize derived similar benefits from *Stylosanthes hamata* cv Verano grown for 2 and 3 years in a fodder bank (Figure 3).

Figure 3. *The effect of cropping history on maize yield with different N applications.*



Providing part or all of an arable crop's N requirement through forage legumes may be an incentive to the farmer to establish fodder banks, which in turn opens up possibilities for sequential crop–forage rotations within fodder banks. Research is being expanded to determine the inputs required to maximise N fixation and the relative efficiencies of different legume genotypes (ILCA, 1983).

Growing dual-purpose grain legumes in rotation with cereals always increases the yield of the latter. Groundnuts in Nigeria seem to be better than cowpeas for increasing the yield of the following cereal crop, presumably because of more rapid decomposition of plant residues and the subsequent availability of N. The difference is probably related to the greater amount of root residues in groundnuts (Jones, 1974).

In Mali, by introducing cowpeas into the crop rotation, millet grain yields have been increased by 60% as compared with those following a first year of millet (ILCA, 1983). Nnandi and Balasubranian (1978) showed that there were differences in root N content among legume species and even cultivars. They concluded that Bambara groundnut and cowpea cv 'NEP 593' were useful in improving the N status of soils even when the top parts of the plants were not returned to the soil.

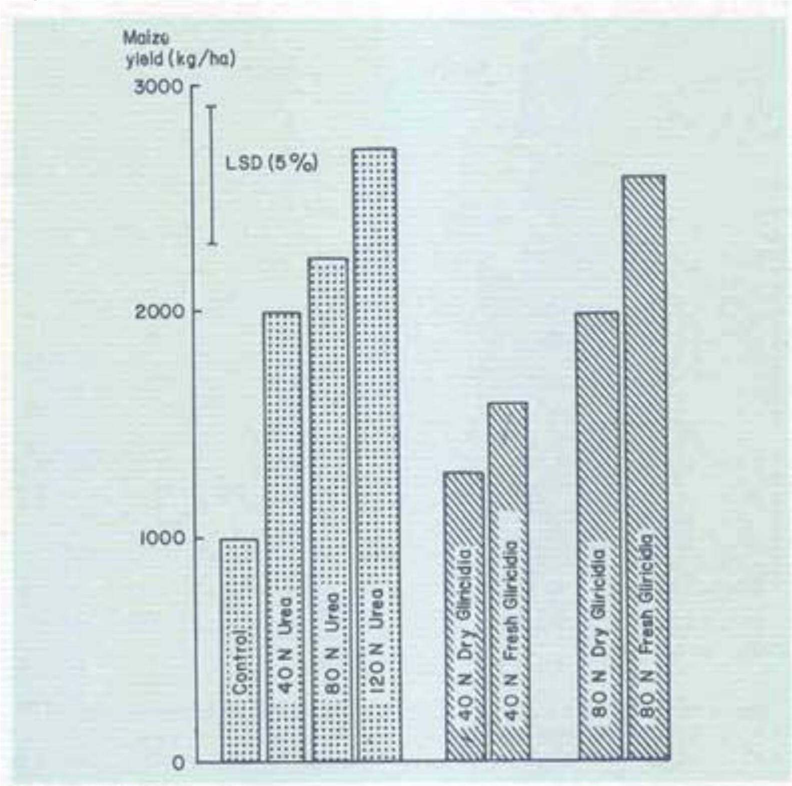
Alley farming

Shifting cultivation, the traditional landuse system in tropical areas, has inspired considerable research into various agroforestry systems in which trees with deep root systems are combined with annual food crops to maximise biomass production and to ensure that large amounts of nutrients and organic material are recycled and returned to the soil. Alley farming, which involves cultivation of food crops between rows of small leguminous trees and shrubs *(Leucaena leucocephala* and *Gliricidia sepium),* is probably the most advanced of the methods and has gained strong support in several areas.

Leucaena leucocephala can fix large quantities of N. In Tanzania, Hogberg and Kvarnstorm (1982) estimated annual N fixation by this species to be 110 ± 30 kg/ha. Higher N fixation values, 500–600 kg/ha/ year have been reported for *L. leucocephala* in Hawaii and Queensland, Australia (Guenarra, 1976; Anon., 1977), although these figures cannot be attributed solely to the legume, as soil N also contributed.

In an alley farm, a high maize grain yield was obtained with the application of 10 t of fresh *Leucaena* prunings per ha or a combination of 5 t of fresh prunings and 50 kg N/ha. The prunings of*Leucaena* as an N source appeared to be more effective when they were incorporated into the soil than when they were applied as mulch—possibly because the mulch loses N through volatilisation during decomposition (Kang et al, 1981). In a comparison between *Gliricidia* and urea fertilizer the addition of fresh and dried *Gliricidia* tops (equivalent to 40 and 80 kg N/ha) significantly increased maize yields. At the lower rate, *Gliricidia* tops were less effective than an equivalent quantity of urea. Although yield differences between fresh and dried *Gliricidia* tops were not significant, the fresh tops appear to be more effective as an N source than the dry ones (Figure 4).

Figure 4. *Gliricidia, either dry or fresh, compared to an equivalent quantity of urea fertilizer.*



Source: Kang (1982).

Other legumes can be used in alley farms. Recent field testing of a fast-growing annual shrub *(Sesbania rostrata)* in association with rice on a hydromorphic site at IITA in 1982 and 1983 revealed its benefits as a source of N for improved rice yields. In the rice yield analyses, *Sesbania* prunings distributed evenly between rows of rice were equivalent to 120 kg N/ha (Table 6). *Sesbania rostrata* is unique for its profuse stem nodulation with 4000 to 5000 nodules on a 3 m high stem compared to less than 50 nodules usually found on the roots of this and most other legumes (IITA,1983).

Table 6. *Effect of Sesbania rostrata prunings and urea on rice yield (kg/ha) at IITA*.

Sesbania Prunings (t/ha)[a]	1982 trial with rice (variety ITA 117); N fertilizer[b]		1983 trial with rice (variety ITA 212); N fertilizer[b]	
	none	added	none	added
0	5760	7610	3010	4790
3	6850	7890	4480	4710
4	7820	7950	4670	4420
Means	6810	7820	4050	4620
LSD (5%)	1080		670	

[a] Total of two prunings collected at 8 and 12 weeks after planting; 3 t/ha in plots planted at spacings of 10 cm x 200 cm, and 4 t/ha in plots planted at 10 cm x 150 cm spacings.
[b] Urea was applied in two splits of 60 kg N/ha each, at 8 and 12 weeks after planting.
Source: IITA (1983).

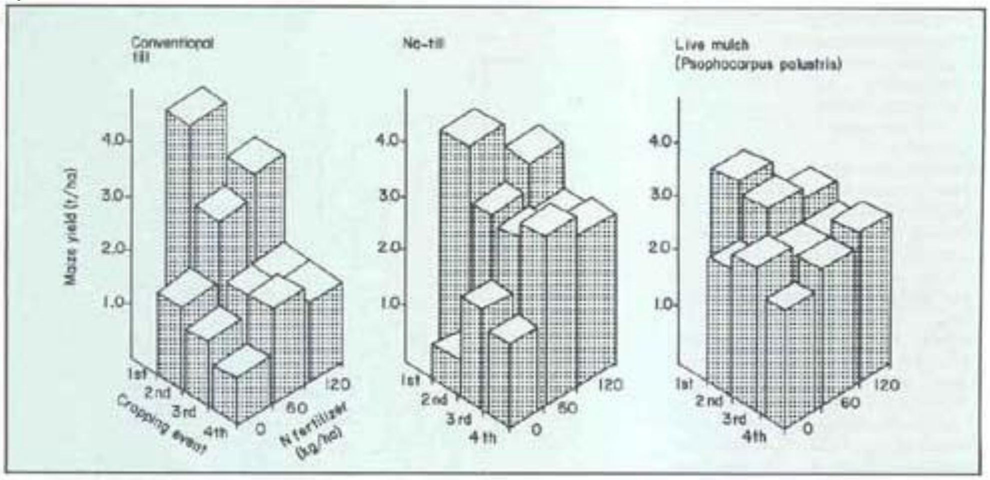
Yamoah et al (1984) observed that prunings from *Gliricidia, Flemingia* and *Cassia* applied before planting maize decomposed by 96%, 58% and 46% respectively during the course of the season, and released the equivalent of 252, 70 and 120 kg N/ha. However, maize grain yield increased by only 15% for *Gliricidia,* 22% for *Flemingia* and 50% for *Cassia,* suggesting that the mulch effect of the slowly decomposing *Cassia* was more beneficial than *Gliricidia's* high N.

Live mulch/cover crops

Although legume cover crops have been used extensively for soil conservation on more than 12 million hectares of plantation crops in Africa, their use in food crop production is of recent origin (Akobundu, 1982). Voelkner (1979) stressed the need for a green legume mulch which could replace the fallow periods and successfully compete with weeds as well as add organic matter and N to the soils.

One way to exploit a legume mulch is to sow directly into the legume cover without tillage. Using this live mulch system with a well established 1-year legume crop, high maize yields were obtained in four subsequent cropping cycles without N fertilizer. A slight yield increase in the fourth season was observed when N fertilizer was added (Akobundu, 1980). Of three production systems investigated—conventional tillage, no-till and the live mulch system—only the last was capable of sustaining high yields at a low N fertilizer input and with minimum weed control (Figure 5).

Figure 5. *A live mulch cropping system is capable of sustained high yields with minimal fertilizer input*.*

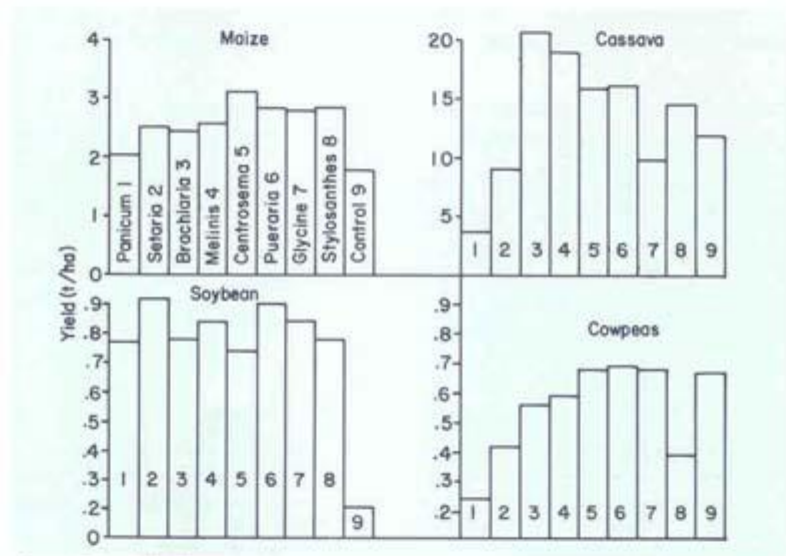


* In the first season a blanket application of compound fertilizer (60 kg N/ha) was made. Plots then received 3 different rates of N.
Source: Akobundu (1980).

Mulongoy and Akobundu (1982) observed that the N contribution from *Psophocarpus palustris* and *Centrosema pubescens* in a live mulch was negative, indicating that they competed with the main crop for available N. However, it appears that the two species nodulated poorly and that their N contribution was low.

The effects of four grasses *(Panicum maximum, Setaria sphacelata, Brachiaria ruziziensis* and *Melinis minutiflora)* and four legumes *(Centrosema pubescens, Pueraria phaseoloides, Glycine wightii*and *Stylosanthes guianensis)* on soil properties and crop production were investigated by Lal et al (1978) in Nigeria using a zero-tillage technique. Two years after establishment *Glycine, Pueraria* and*Centrosema* had improved soil organic matter, total N content and cation exchange capacity (CEC). Maize and soybean responded to all species while cowpeas suffered yield reductions when the grasses and *Stylosanthes* were the sod species. Cassava showed a mixed response, with *Setaria, Panicum* and *Stylosanthes* being associated with lowered yields (Figure 6).

Figure 6. *Effects of different cover crops on yields of four food crops.*



Source: Lal et al (1978) and Lal (1983).

Similarly Lal et al (1979) studied the effects of three grasses *(Brachiaria, Paspalum* and *Cynodon spp.)* and five legumes *(Pueraria, Stylosanthes, Stizolobium, Psophocarpus* and *Centrosema)* on an Alfisol. Compared with fallow weed control, total N content was significantly higher under *Stylosanthes, Stizolobium* and *Psophocarpus*. The *Stylosanthes, Cynodon, Centrosema* and *Psophocarpus*also improved soil organic matter, CEC and exchangeable bases.

Legume fallows and green manure crops obviously provide a large amount of N for subsequent grain crops but have not been widely used in sub-Saharan Africa; probably because farmers do not want to devote a whole crop season to N accumulation.

Natural/sown pastures

There is substantial evidence of N accumulation under legume-based pastures in Africa. Table 1 provides a summary of the amount of N that can be fixed in any given environment. In terms of farming systems it is on smaller holdings that the incentive to fully utilise a sown pasture technology is greatest and where such sowings expand most rapidly. The major constraint here is often the ability to borrow or generate the necessary finance to undertake the development, and the provision of appropriate low-interest public funds can be a great incentive to speed up this development (Cameron and Burt, 1983).

Conclusion

From the evidence accumulated over the last 40 years it can now be concluded that the use of forage legumes is the best method of injecting biologically fixed N into the farming system. Between 50 and 400 kg/ha of N can be fixed each year and this N makes a significant contribution to soil fertility, pasture yield and its associated animal production, and any following food crop. Its monetary value can be extremely large. It seems that such an approach would be of particular value in sub-Saharan countries; certainly once the relevant legumes have been domesticated, it would produce cheap and long-lasting beneficial effects.

Research direction

- This review highlights the potential for significant N fixation by forage legumes. However, further research in the following areas is necessary to exploit fully their potential:
- Some rhizobium strains are more heat-tolerant than others. What adaptive mechanisms have been developed by the rhizobia and/or host plants to ensure effective N fixation under high soil temperatures? Does the level of soil organic matter affect nodulation and is there any interaction with temperature?
- Both water deficiency and excess are major factors limiting plant growth and N fixation. Root infection and N fixation of forage legumes in waterlogged and drought conditions are little understood.
- A considerable number of legumes are indigenous to sub-Saharan Africa but they have not been systematically evaluated against introduced material. Similarly, inadequate attention has been given to their nutritional requirements. Clearly, there is a need for more definitive studies on the nutritional factors limiting N fixation in forage legumes in general, and in those legumes that have a potential in farming systems in particular.
- In a similar vein little attention has been paid to the effects of nutritional factors on nodule activity in forage legumes. Selection of acid-tolerant rhizobium strains, for acid soils, and the selection of strains adapted to low levels of fertility are two obvious areas of study. The quantitative limitations of nutrient deficiencies and excesses on N fixation also need further study. For example, is nodulation adversely affected by high soil nitrate levels at the start of the wet season?
- Nitrogen fixation by forage legumes in cropping systems needs to be monitored in order to assess their N contribution to the crop plant.
- Does the reduced light intensity in mixed/intercropping systems always reduce nodule activity?
- Alley farming with Leucaena has shown a low transfer rate of N from the legume to companion crops. A better understanding of the N flow in such a system is needed to identify the main losses and to suggest ways for the more efficient capture of N. As part of this research the N-release pattern of decomposing prunings needs to be studied so that appropriate recommendations can be made.
- The increased use of forage legumes, legume fallows and green manures will demand studies into the introduction of economically and socially acceptable cropping systems.

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