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# The role of legumes in farming systems of sub-Saharan Africa

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## Abstract

Legumes have played an important role in raising productivity of farming in the temperate zone. The challenge is to demonstrate a similar role for the tropics. The primary role of legumes is in fixing atmospheric N<sub>2</sub> leading to their capacity to (1) build soil fertility and (2) enhance forage and mulching quality.

Ecologically, legumes are largely species of successional habitats and thus, to maintain stable legume-based associations, management is a necessary input. The effectiveness of legumes in biological N<sub>2</sub> fixation is very variable, depending on environmental, nutritional, biological and genetic factors. Therefore, their effect on soil fertility is also likely to be variable and substantially under management control.

The contribution that legumes can make to herbage quality is considerable and there is ample evidence of substantial gains in animal production being possible. They also have high mulching value for crop production. Farming systems in most of sub-Saharan Africa are substantially different to those in Australia or much of tropical America. In most of Africa, small-scale, mixed crop-livestock farming systems are the norm, with the two components being closely integrated. In a variety of such systems legumes are being found that can be integrated into both the crop and the livestock component. In systems with minimal fertilizer inputs, legumes can contribute to the crop phase by reducing the rate of soil fertility decline, or even enhancing crop yield, as well as reducing the length of the fertility-regenerating fallow period. In the pastoral phase, legumes contribute to better quality and use of crop residues and of natural forages on fallow lands. A variety of farming systems are discussed for the humid, subhumid and semi-arid agro-ecological zones.

Many factors govern the all-important management aspects of legume intervention. The most important is the management of nutrients, as they determine the ultimate level of productivity. This not only depends on the actual level of the nutrients, but also their rate of circulation. In this respect, farming systems could be viewed in a more organismic or ecosystem framework than is presently the case.

## Introduction

That legumes have a role to play in farming systems has been overwhelmingly demonstrated in temperate zones, first in Britain and later in temperate Australia and New Zealand (Tothill, 1978). However, while legumes could play the same role in farming systems of the tropics, and particularly of sub-Saharan Africa, their adoption has not yet had the revolutionary impact that it has had in temperate regions. The objective of this paper is to examine what might be the main limiting factors to an equally, or potentially more dramatic revolution in sub-Saharan Africa. Firstly, we must re-examine closely the role of legumes and then look at the farming systems to ascertain how legumes could be used. Also, we must pay particular attention to management because, as has been shown in many situations, we can only do better than nature if we throw in a substantial measure of management and this is often overlooked.

## The role of legumes in farming systems

The role that legumes can play in farming systems has been covered by a large number of contemporary reviews, notably Wilson (1978), Mannerje et al (1980), Norman (1982), Crowder and Chheda (1982), Hague and Jutzi (1984) and Agishi (1985).

The primary role that legumes play is to fix atmospheric  $N_2$  through their symbiotic relationship with *Rhizobium* spp., usually associated with the host's root system. This contributes nitrogenous compounds to the soil, either directly, by nodule excretion, or indirectly, by decomposition of root nodules and tissues. Nitrogen is also passed to the soil from the top growth through litter fall, though leaching by rain from above-ground parts and by deposition of excretory materials from herbivores both above and below the ground.

This primary role of fixation of atmospheric  $N_2$  leads to two dependent or consequential roles of legumes: (1) their capacity to increase soil fertility and (2) the generally high levels of protein in the herbage and hence its high forage or mulching quality.

It is unlikely to be by chance that most legumes have acquired their ability to fix N. If we examine the ecological basis for the natural distribution of legumes in the world's floras, one very seldom finds them at all common or highly productive in climax vegetations. However they are frequently common and vigorous in successional situations, particularly where soil fertility or the availability of plant nutrients is low (Norris, 1964). Thus legumes are often strongly associated with disturbed sites (e.g. road-sides). As a result of this disturbance, when nutrients other than N are likely to be more available than usual, legumes compete effectively against those species that cannot fix N. This is presumably why most legumes retain a capacity to respond to such important secondary nutrients as P, since this is critically important for effective symbiosis.

## Biological nitrogen fixation

Haque and Jutzi (1984) reviewed the factors that may limit biological N fixation. Since  $N_2$  fixation is the product of two symbiotically interdependent organisms (the host legume plant and the bacterium), it may be affected by the reaction of one or the other or both. As a broad generalisation, fixation is proportional to the vigour of the host plant and therefore is affected by the factors that affect plant growth, i.e. water, temperature, nutrients and light. This generalisation may be upset by factors that specifically affect the activity of the rhizobium rather than the host. These may be temperature, soil pH, nutritional status (particularly N and Mo) and genetic specificity.

It is not surprising, therefore, that measurements of the amounts of N fixed vary quite widely. Haque and Jutzi (1984) tabulated some fixation rates from different parts of Africa for a range of legume species (Table 1). These values range from 34 to 395 kg N/ha, with four species

averaging over 200 kg/ha. Mannetje et al (1980), in their review, quote values of 47 kg N/ha per year over a 26-year period on temperate Australian *Trifolium subterraneum*, 30 kg N/ha per year over a 10-year period on a grazed *Stylosanthes humilis-Heteropogon cortortus* pasture in the tropics and 280 kg N/ha in 4 months from *Centrosema pubescent* in sand culture in Malaysia.

**Table 1. Some nitrogen fixation rates for tropical forage legumes in sub-Saharan Africa.**

Legume	Range (kg/ha/year)	No. of records
<i>Centrosema pubescens</i>	84-395	3
<i>Desmodium uncinatum</i>	17 8	1
<i>Leucaena leucocephala</i>	110-600	4
<i>Stylosanthes guianensis</i>	94-290	3
<i>Trifolium semipilosum</i>	80	1

Source: Haque and Jutzi (1984)

These results indicate that, over a wide range of conditions, legumes can fix significant but varying amounts of N. However, these amounts need to be equated over time because varying proportions are cumulative in different soil compartments. This is also an important consideration because N may accumulate in the soil in organic, biological or inorganic ( $\text{NO}_3$ ,  $\text{NH}_4^+$ ) forms. In some situations (e.g. heavy clay soils), total N fertility may increase steadily whilst available N fertility declines because of the build up of micro-organisms that compete successfully for available N. Eventually a situation is reached where the high-fertility soil becomes apparently as infertile as an inherently low-fertility soil. Studies by Mohamed-Saleem and others (this volume) indicate that plant responses to the build-up of soil fertility are not accounted for by N levels alone. It appears that the effects on overall soil biology, in terms of lower bulk density, higher infiltration rate and more rapid nutrient turnover, are important.

## Effects of legumes on herbage quality

Legumes have long been known to be highly nutritious for both humans and animals. As expected, the fixation of N leads to generally higher protein levels in the plants' tissues. Mannetje et al (1980) (Table 2) reported crude protein levels in temperate legumes, tropical legumes and tropical grass of 23.5, 21.2 and 12.2%, respectively, when grown under identical controlled environmental conditions, even though the grass received 112 kg N/ha in 4 months. Dry-matter digestibilities of the three groups were 76, 72.8 and 70.5%, respectively. Phosphorus concentrations of the tissues were similar.

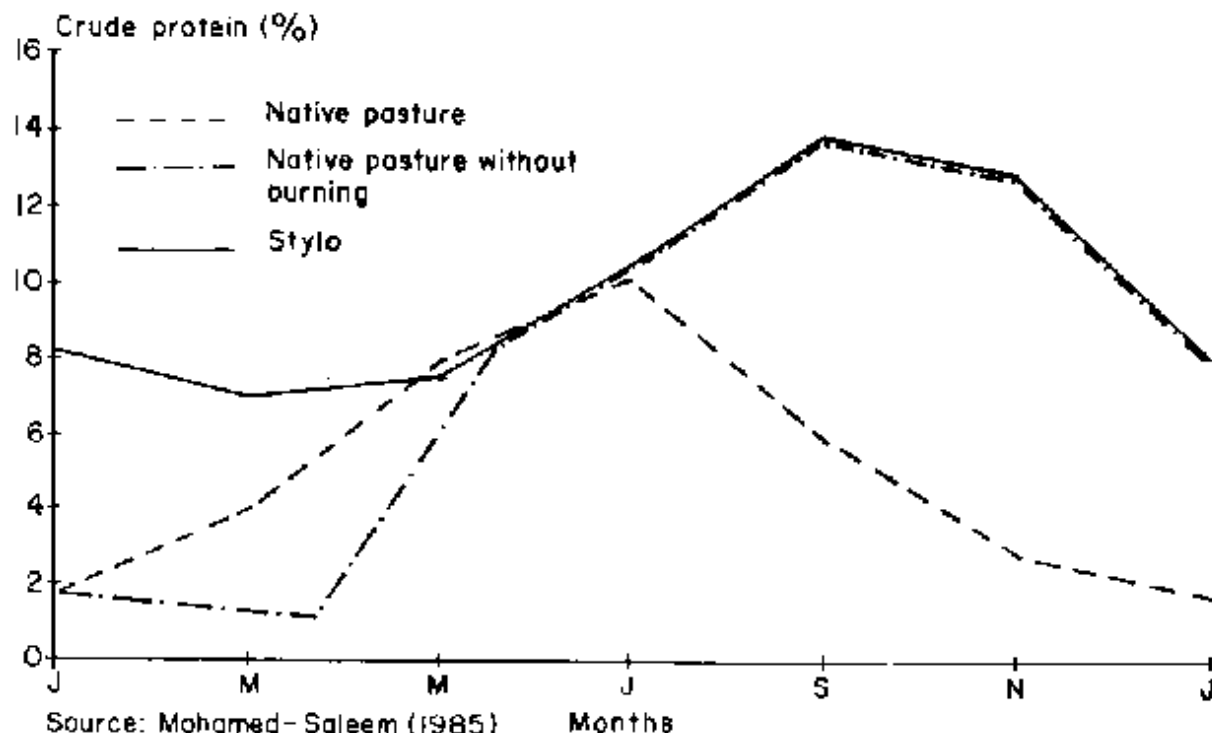
Because of the initially higher levels of protein in the legume tissues, it takes longer for their protein content to fall to less than 6.5%, the lower protein threshold for animal maintenance, thus prolonging the period during which its forage value is high (Figure 1). Dry-season burning can improve grass quality under conditions of residual soil moisture, but this is slight compared with residual legumes. Legumes have tap roots and therefore usually root deeper than grasses. Thus they often remain green longer. The seeds are often a further source of high-quality feed. However, late season grazing can interfere with seed set and reduce the amount of seed available for re-establishing the legume in the following season.

**Table 2. Quality components of forages grown under identical controlled environments.**

	Temperate legume	Tropical legume	Tropical grass + N
Crude protein (%)	23.5	21.2	12.2

Source: Mannetje et al (1980).

**Figure 1. Annual crude protein profiles for native pasture and *Stylosanthes* grown in fodder banks in Nigeria.**



The quality and protein content of the herbage also determines the effectiveness of the material as mulch. Similar factors seem to affect the rate of decay of litter and mulch as affect the digestibility of the material. *Desmodium intortum* is generally less digestible than other tropical and temperate legumes (Whiteman 1980), and decomposition rates of *D. intortum* litter is also slower than other legumes.

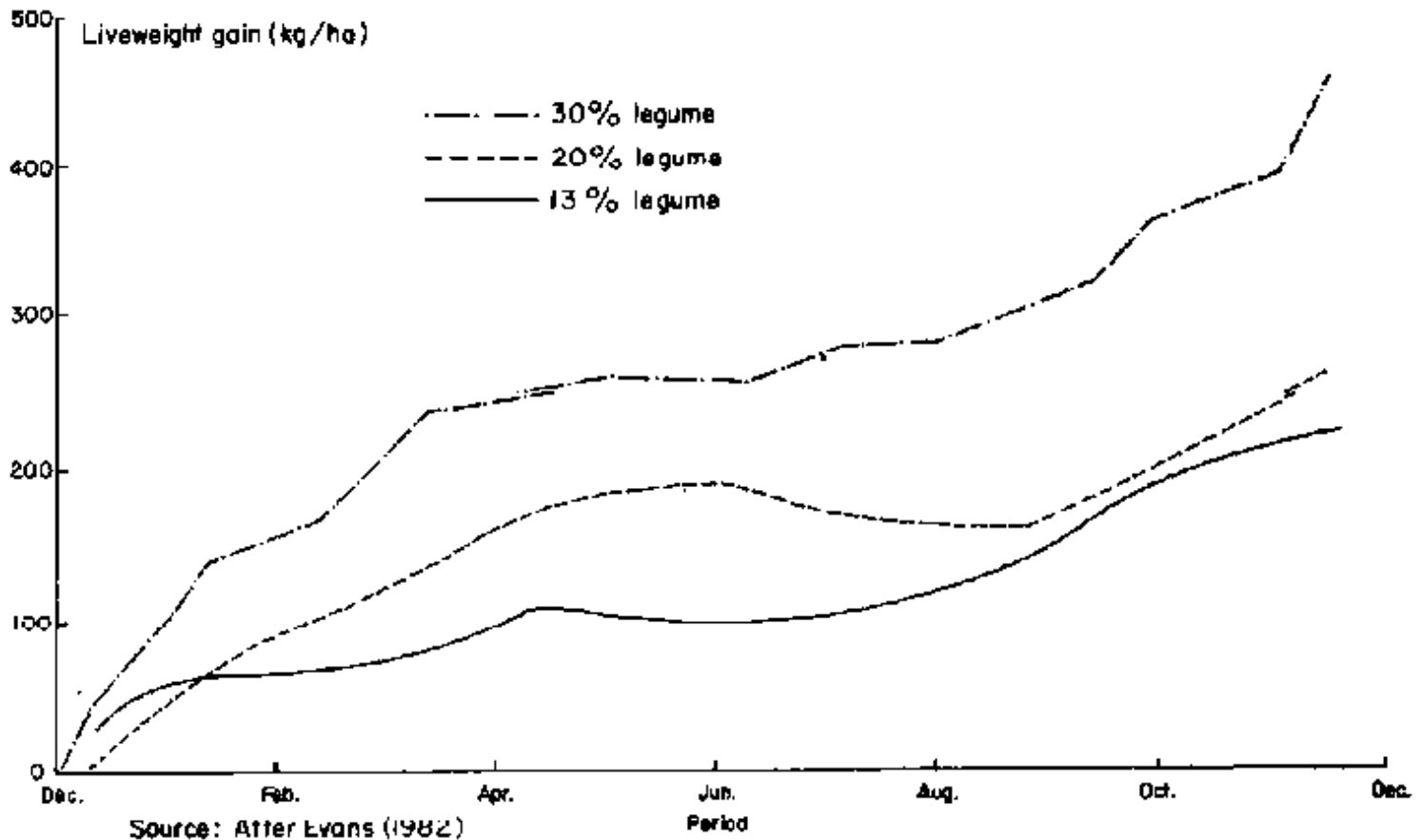
The use of forage legumes as intercrops, relay crops, or live-mulch cover crops relies on the ability of the legume to supply N to an associated or subsequent crop. All of these applications are essentially still at early experimental stages (Powell, 1985; Mohamed-Saleem, 1985), although intercropping with pulse legumes is a common practice. Animal production can be integrated with some of these systems. The Australian legume-ley-farming model based on the sheep-wheat production system in temperate Australia is being investigated in northern Australia and East Africa and seems promising (McCown et al, this volume). Hague and Jutzi (1984) report several studies giving values of 40-100 kg N/ha released following several years of forage legume cropping.

Another model involving animals is that of the development of fodder banks comprising pure stands of the legumes *Stylosanthes guianensis* and *S. hamata* on fallow land as a dry season supplementary grazing resource. Mohamed-Saleem (1985) estimated that a fodder bank releases 45-60 kg N/year to a subsequent crop.

## Increasing animal production

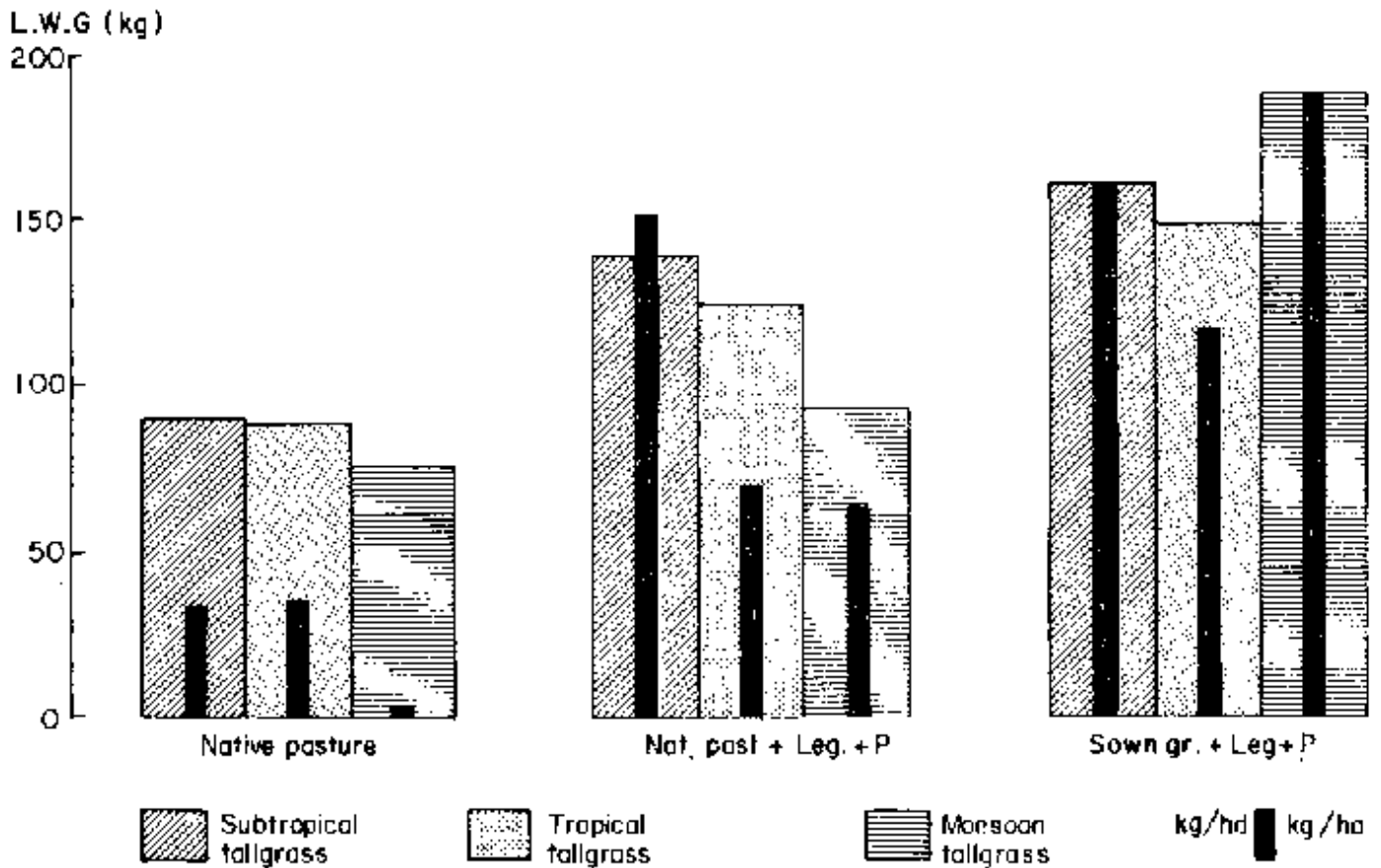
The greatest constraint on animal performance in Africa and elsewhere in the seasonally dry tropics is the low nutritional value of most animal feeds during the dry season. Evans (1982) showed that liveweight gain of steers was directly proportional to the proportion of legume in pasture (Figure 2).

Figure 2. The effect of legume content on liveweight gain of steers.



A great many trials have studied the effects of legumes in the diet on animal production. Of 24 studies from West Africa using various species of *Stylosanthes*, almost all showed significant increases in animal production through feeding legumes (Lazier, 1984). However, Clatworthy (1984) found a less marked effect of legume feeding in a review of studies in southeast Africa, which he attributed to generally better performance of animals on native pastures. Gillard and Edye (1984) and Tothill et al (1985) found similar results in reviews of experiments in northern Australia (Figure 3), as did Whiteman (1980) in a study of results from five countries (including 2 African) with a variety of legumes.

Figure 3. The effect of legume on animal liveweight gain (LWG) in the Australian savanna regions (hatched histograms kg/hd, bars kg/ha). The information was derived from 19 studies over 20 years.



Source: Tohill et al (1985).

## Farming systems in Africa

Farming systems in Africa can be classified into broad general groupings (Figure 4). Increasing population pressure is causing changes in these farming systems because most of them rely on a relative abundance of land. The pastoral systems traditionally relied on wet season and dry season grazing lands, and people and animals moved back and forth between them (nomadic/transhumant). Similarly, arable systems originally relied entirely on shifting agriculture; when the fertility of the soil declined the farmer moved on and cleared another area. As a result, a relatively large proportion of the land was out of production at any one time and was therefore available for grazing.

Figure 4. *Farming systems in Africa.*



The problem is how can such interventions be made? At what cost? How much will the present systems have to be modified? And what kinds of plants should be used? To answer these questions we need to consider the solutions by agroclimatic zones, as different constraints apply in the different zones.

### **The humid zone** (> 1100 mm average annual rainfall)

The humid zone encompasses the forest and transitional Guinea savanna zones. The high incidence of trypanosomiasis in the humid zone is a major constraint to livestock production. Small ruminants, which have reasonable tolerance to this disease, are the main livestock used (Sumberg, 1984).

Traditionally, "slash and burn" shifting agriculture was the predominant system but agriculture is now based largely on rotational woody bush fallow of up to 10 years (FAO, 1983). In Africa these practices do not seem to have had the same serious effects as in Southeast Asia, where the forest succession has been arrested by the invasion of a poor-quality grass (*Imperata cylindrica*) and the land rendered useless for anything but poor-quality grazing. Much of this land is now being reclaimed by planting *Leucaena leucocephala*. After 3 years the *Imperata* is shaded out and soil fertility is on the way to being restored. The leucaena provides forage, fuel and timber and is leading to a new farming cycle (NAS, 1977). In other areas leucaena is being planted on terraces and the herbage used as mulch to prevent the degradation of the land; it also provides animal feed (Sastrapradju, 1985).

Leucaena is also being used in Africa, in the alley farming system developed by IITA and ILCA. In this system the browse species *L. leucocephala* and *Gliricidia sepium* are grown in rows 5 metres apart with crops planted between the rows. The leucaena and gliricidia herbage is used to mulch the crops and to supplement the diet of animals (Atta-Krah, this volume). This system is already being accepted in Nigeria. Terrace farming using leucaena is already a widespread practice in the Philippines, Indonesia and Sri Lanka. However the extent to which it can be applied in highland areas, particularly in Ethiopia, will depend on the identification of vigorous browse species for temperate conditions. In the Ethiopian highlands it appears that *Sesbania* spp. may replace leucaena in alley farming or terrace farming.

The Australian (Teizel and Middleton, 1983) and South American (Sanchez and Tergas, 1979) models of pasture improvement in the humid tropics by means of replacing the native pastures with grass/herbaceous legume mixtures would appear to have little application to farming systems in sub-Saharan Africa. Their most likely application is in dairy production systems near to the larger population centres.

Another farming system that is fairly widespread in the humid tropics is specialised cash cropping with plantation crops such as oil palm, cocoa, rubber, coconuts, bananas etc. This may be large scale, as with plantation estates, or small scale, as part of smallholder mixed farms. This is a potentially important area for the improvement of livestock feeding through intercropping with forage legumes but has been neglected in Africa due to trypanosomiasis (FAO, 1983), although it has received much attention in Southeast Asia (Plucknett, 1979; Whiteman, 1980).

### **The subhumid zone** (approx. 900-1200 mm average annual rainfall)

The subhumid zone is characterised by a fairly marked alternation of wet and dry seasons. Smallholder mixed farming predominates, the main crops being maize and sorghum, but the subhumid zone is still substantially underutilised and is suitable for a wide range of crops. In west Africa the integration of pastoralists and crop farmers is most active in the subhumid zone (FAO, 1983), and agropastoral systems (pastoralists becoming sedentary and growing crops or agriculturalists taking on animals for integrated pastoral production) are emerging.



In such systems, which represent an intensified phase of agricultural production, the low protein content of forage (natural pasture or crop residues) is a severe constraint on the dry-season nutrition of animals. Soil fertility limits crop yields, and maintenance of soil fertility in crop lands and restoring the fertility of fallow lands are problems. All of these constraints could be more or less alleviated by introducing forage legumes.

Based on earlier work carried out by NAPRI (Haggar et al, 1971) the forage legumes *Stylosanthes guianensis* and later *S. hamata* were identified as promising for use in improving animal performance over the dry season. This work emphasised the advantage of growing small areas of legumes to provide supplementary feed rather than oversowing native pastures, as was being carried out in Australia. Subsequently this idea was put into practice in the form of fodder banks (Mohamed-Saleem, this volume). The reasons for not continuing with the Australian model were (1) the difficulty of managing the legume adequately under a communal grazing system; (2) the difficulty of controlling fires and (3) the relatively poor cost/price situation and its unpredictability. It is very much constrained by fertilizer price, seed price and market type and stability (FAO, 1983).

Fodder banks can be used in pastoral-oriented systems to improve forage quality for livestock and to restore the fertility of fallow land. They also have application in the crop-oriented system in their effect on crops grown on these areas (Mohamed-Saleem, 1985). A further intervention related to this is the introduction of the legume as an intercrop in the existing cropping system, as a means of reducing the rate of fertility decline, as well as bolstering the nutritional value of the crop residues for animal feeding. Mohamed-Saleem (1985) has shown that, if the sowing or spontaneous regenerative growth of the legume is delayed by 3 - 6 weeks after the crop is sown, the legume has very little effect on the crop yield, while the yield of the crop in subsequent years may be increased by 10%.

Although the potential for alley cropping in this zone seems to be largely untested, the climate is suitable for leucaena. In Australia, leucaena is being used successfully as the principal component of fodder banks on suitable soils in some seasonal environments with as little as 700 mm average annual rainfall. It is likely that as population pressure increases in the future, with further pressure being brought to bear on the length of the fallow period, alley farming or terrace farming will become more widely adopted.

### **The semi-arid, Sudano-sahelian zone (<800 mm average annual rainfall)**

In contrast to the subhumid zone, cereals are the predominant crop in the semi-arid zone, and the animal population density is higher because of the absence of tsetse fly and trypanosomiasis and the proximity to pastoral areas. The zone is characterised by more extreme seasonality than the subhumid zone: the dry season is longer, and the growing seasons are unreliable, particularly with respect to the onset of the rains. The long dry season is an important constraint to livestock production, and crop production is constrained by the need for short-season varieties. Apart from this, the farming system is essentially an extension of the subhumid-zone type.

In the semi-arid zone leguminous crops (e.g. cowpeas, beans, groundnuts) are traditionally grown as intercrops with cereals. This provides both a high-value food grain or oilseed and a high-protein crop residue for dry-season feeding. The contribution of the legume to the N economy of the system is less clear. Indications are that pulse legumes contribute rather less to soil-N build-up than do forage legumes.

Where animal production is an important enterprise and there is a strong incentive for improving the dry-season nutrition of the animals, a forage legume, grown either as an intercrop or in rotation, may be more valuable than a grain legume. It is likely that for the latter to be true, the contribution to soil N by the forage crop must be substantially higher than that by the grain legume. Research aimed at testing this is being conducted in tropical Australia (McCown et al,

this volume; Chamberlain et al, this volume), and is planned for projects in Kenya and in northern Nigeria

Other types of legume innovations must rely on longevity (perenniality) and drought tolerance. For smallholder, mixed-farming systems browse legumes can be grown in small plots or around the compound, particularly if they can be watered.

Broadacre planting of drought-tolerant browse legumes on rangeland is unlikely to be a practical innovation, due to the problems of communal land tenure and lack of proper management. It is all too easy to either destroy the introduced legume or, through the innovation, to destroy the natural grazing resource because of inadequate management.

One of the philosophical considerations with dryland areas is that one changes from viewing interventions as a means of raising productivity by improvement on a broadacre basis to one of directing interventions to selected favoured sites and thus raising productivity selectively. Current studies on rangeland pastoralists indicate that this is exactly what is happening (Cossins, 1985; de Leeuw, personal communication). The best use of legumes would seem to be in developing forage grazing or fodder banks with perennial woody species or perhaps in enriching seasonally flooded cropping or natural forage areas with self-regenerating annuals. However, the role of legumes in the increasingly wide case of irrigation has not been dealt with here.

## Supplementing residues and byproducts with legumes

One role of forage legumes that could be common to all the zones is as a feed supplement with crop residues and agricultural byproducts. Some of these residues and byproducts are used mainly as mulch or are burned, e.g. sugar-cane tops, cocoa husks, coffee hulls. Supplementing some of these with urea/molasses can render them suitable for at least a maintenance feed for livestock, and their feeding value can be further enhanced by supplementing them with a leguminous forage (Preston and Leng, 1986).

## Management of legume- based interventions

The introduction and maintenance of legumes in any farming system must be accompanied by enlightened management. If the intervention is novel for the situation or the environment then the management must be researched and learned. All too often the legume, once introduced, is taken for granted, particularly in the case of forages. Farming and pastoralism are intrinsically management of various resources and innovations to productive advantage. In grazing systems, management of the forage resource must be exercised through control of the grazing animals.

Africa is almost unique in that animals are herded daily. Apart from India, almost everywhere else they graze untended, except for dairy animals. This offers an opportunity for managing forages far more effectively and intensively in Africa than is possible in most other areas. One of the main reasons for failures of pastoral legume interventions is poor management. An important exception to this is the occurrence of disease, e.g. *Colletotrichum gloeosporoides* (anthracnose) in certain *Stylosanthes* spp.

In many cases management requires a much deeper understanding of the ecology of the situation than can be achieved by empirically-derived manipulations (Tothill, 1978). This was discussed extensively in the symposium on "Plant Relations in Pastures" (Wilson, 1978). Management is the means by which a particular ecological balance between vegetation and grazing animals is maintained. However, the basis for that management must also be understood.

## Management and soil fertility

An example of managing the balance between vegetation and grazing animals through manipulating soil fertility can be drawn from Australia (Tothill and Mott, 1984). In the northwestern tropics, it has been found that introducing legumes into the native pastures increased animal production by up to a factor of 10. In this situation the increased grazing pressure that the legume allows causes the native grass species to disappear and unpalatable weeds to replace them unless improved grasses are also introduced. However, in the southeastern tropics, native pastures, when improved with legumes, behave quite differently. The native grasses do not disappear but their proportions in the pasture change, with an increase of those that can tolerate heavy grazing and that also respond to conditions of higher soil fertility. While these two environments contrast in terms of extreme seasonality of rainfall vs moderate seasonality, they also differ significantly in terms of soil fertility. There are indications that the availability of plant nutrients for growth, coupled with the rate at which they are cycled in the ecosystem, strongly affects the pastures' response to livestock management.

Other Australian work has identified legume strains that are adapted to low soil P levels (Jones, 1974). Growing these legumes on low-P soils results in nearly pure legume stands, with little invasion of nitrophilous grasses; however, for these pastures to support adequate animal performance, the animals must be provided with supplementary minerals, such as P and S. in salt-lick form (Winter et al, 1985).

### **Management and palatability**

Another factor that affects grazing management is the palatability of the forage. Stobbs (1977) indicated that legumes are generally less palatable than grasses when both are green. Grazing animals generally prefer grasses to legumes during the active growing season but that preference switches to legumes as the grasses mature. This switch of preference can have an adverse effect on the regenerative capacity of some legumes if it occurs before the legume sets seed; therefore care is needed in managing such legumes. *Leucaena* is an exception to the above generalization, as animals prefer it to grasses at any time of the year; thus the access of the animals to *leucaena* must be controlled, either by rotational grazing or by ration grazing.

Perhaps one of the reasons for the slow acceptance of *leucaena* is the relative difficulty of managing it in ranch-type systems. This problem, and that of mimosine toxicity, largely disappear in systems in which animals are herded daily.

### **Management and demographic/phenological factors**

I have already touched on how maturity time may interact with seasonal changes in grazing preferences in terms of the reproductive performance of legumes. The responses of the legume to this interaction depends on whether the plant is annual, perennial or something between. General experience shows that, in seasonally wet/dry climates, mostly associated with the subhumid and semi-arid zones, the plant should be able to regenerate vigorously both from seed and from established plant crowns, giving the plant two options for survival. Following severe droughts most or all of the regeneration will come from seed, whereas in benign years it will come from regrowth from the crowns.

Monitoring plant populations is therefore an important part of management research (Jones and Mott, 1980), and also allows the interaction of management and climate to be monitored. Phenotypic characteristics of plants are also important management considerations. Twining legumes such as *Macroptilium atropurpureum*, *Centrosema* spp. and *Neonotonia wightii* must be substantially more leniently grazed than those of erect habit such as *Stylosanthes* spp. or of low prostrate habit such as *Lotononis bianesii* or *Trifolium* spp., due to their difference in growth habit.

### **Socio-economic factors**

These are far more complex in African farming systems than in wholly commercial systems elsewhere, e.g. in Australia, much of South America, etc. Not only are there cultural considerations but also the animal is so closely integrated into the smallholder, mixed-farming system and is an essential part of the subsistence of the people within that system.

One of the most important constraints to management almost everywhere in Africa is that of labour, which at first would appear to be paradoxical. However with all the cropping-based systems there are severe bottlenecks at crop planting and weeding. All other operations must be overlooked at these critical times. Animal-related work, such as cultivation and sowing of forage plots and their weeding, will receive very low priority in the assignment of available labour. This is particularly the case in West Africa where animals have only recently been incorporated into crop-based systems.

Another important consideration is the way in which animal products can be marketed. In basically non-cash economies quite different forces operate on the production system than in cash economies. This can often place an upper ceiling on the development of one component of an enterprise. The extent to which specific forages are grown will depend very much on the value of the produce, either in terms of cash or its internal value.

As has already been said, population density or pressure has a marked effect on farm operations. While labour is the basic constraint on farm size everywhere, population density is really the main determinant of the length of the fallow phase and, therefore, affects both the area of land not being used at any one time and the degree of fertility regeneration taking place. Obviously if productivity is to increase, fertility must also be increased to match the offtake of nutrients that will follow. If the soil is not naturally fertile, this can only be done through inputs of fertilizer or by including legumes in the system, i.e. in the cropping or fallow phase, or into animals in the form of mineral supplements or slow release implants. The rate at which nutrients circulate within the system determines how efficiently they are used, and it is the essential nutrients, particularly N, that drive the system.

This is a fascinating area of farming systems research which has, as yet, been hardly scratched. It is essentially looking at a farming system in an organismic or ecosystem framework.

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