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Nitrogen fixation by forage legumes

Evaluation of *Stylosanthes* in Nigeria

Integrated surveys of pastoral production systems

Pastoralism and milk production

ILCA's computer facilities

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Preface

The articles in this issue range from the very specific to the very general. The longest and most comprehensive paper reviews the many and varied problems associated with the exploitation of legumes in Africa. In other parts of the world legumes have served to boost both animal and crop production. In Australia, for example, a combination of subterranean clover *(Trifolium subterraneum)* and superphosphate is the cornerstone of an integrated cropping–livestock system that has transformed what were previously considered to be low-potential lands into valuable farming country. A similar transformation could occur in sub-Saharan Africa but there are many climatic, edaphic and biological factors that intrude on the successful establishment of legumes. The authors describe some of the problems that have been or can be expected to be encountered, and couple this with a general discussion of the role of legumes in crops and pastures.

On a more specific level, one legume which has achieved some success in African pastures is *Stylosanthes hamata* cv Verano. It has many of the attributes needed in a demanding environment: it is deep-rooting and drought-tolerant, seeds well yet is also a facultative perennial, tolerates heavy grazing and provides a dry-season store of standing hay. Above all else, it is resistant to the anthracnose disease that has hindered the exploitation of other valuable *Stylosanthes.* Verano stylo has the potential to be used widely throughout sub-Saharan Africa but the emergence of new virulent strains of the anthracnose fungus could abort any possible improvements in farm output. As a safeguard ILCA scientists have been screening other *Stylosanthes* spp*.* that could substitute for Verano if it ever became susceptible to anthracnose; their preliminary findings are discussed in the second paper of this *Bulletin* issue.

The third paper deals with the collection of data in the various ecological zones of sub-Saharan Africa. Again, it ranges from the very broad—the use of satellite imagery—to the specific—the use of ground teams to elicit information that can be correlated with, and supplement, the information provided by both satellite and aerial surveys. The authors, who have considerable experience in this field, make suggestions on how the three tiers of data collection—satellite, air and ground—can be integrated in a more effective manner.

The fourth article describes milk production in pastoral situations. The value of milk to pastoralists is often neglected in rangeland development. The author describes how milking livestock are exploited and the effects of this exploitation on animal performance in the pastoral environment.

The last paper in this issue is an unusual departure for a publication that concentrates on the many facets of animal and plant production. However, ILCA has in many respects been a pioneer in expanding scientific computing in the region. ILCA's experience in developing a modern computer network, the problems encountered, the rationale behind the many decisions that have to be made, are a lesson for any other organisation contemplating the often difficult task of confronting the computer revolution. ILCA has done so successfully, and the authors describe the process, how the systems work, and outline the sort of services that the computer unit offers to outside users.

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

[*] This is an up-dated version of a synthesis paper presented at the First Conference of the African Association for Biological Nitrogen Fixation, held in Nairobi, Kenya, 23–27July 1984.

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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

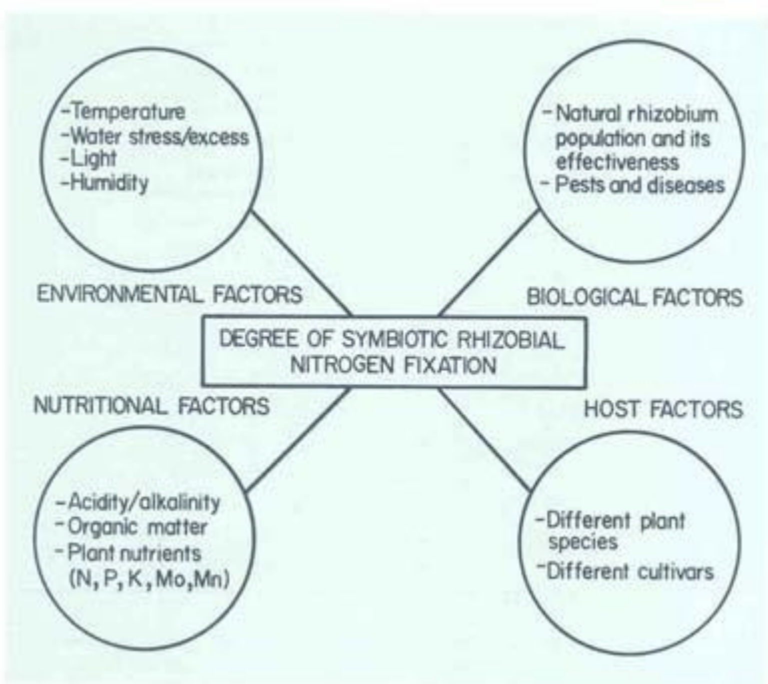
Acacia pennatula	A	34
Gliricidia sepium	A	13
Inga jinicuil	A	35
Leucaena leucocephala	C	500–600
	A	110
Casuarina equisetifolia	B	58
	D	>260
	I	46[a]
Allocasuarina littoralis	B	218

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

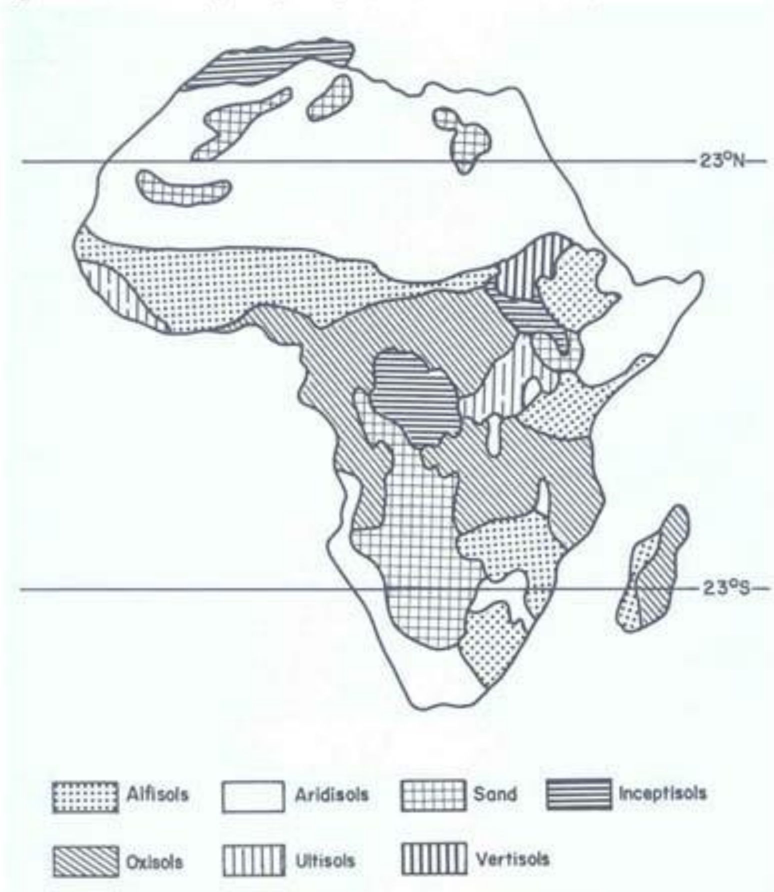
Both photoperiod and light intensity have been reported to affect nodulation and N fixation (Gibson, 1977). The effects of light on N fixation seem to be associated with variations in host plant photosynthesis. Under shaded conditions, i.e. when forage legumes are intercropped or in a mixed pasture, 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.

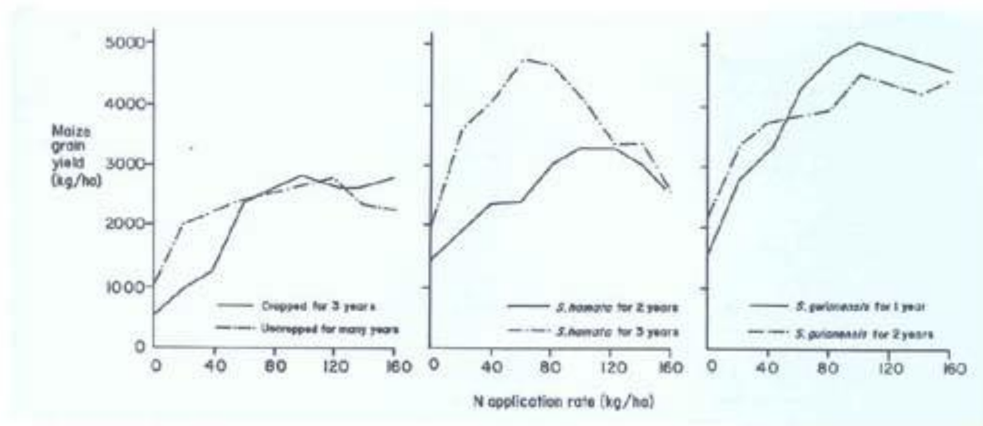
Legume–cereal cropping

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.

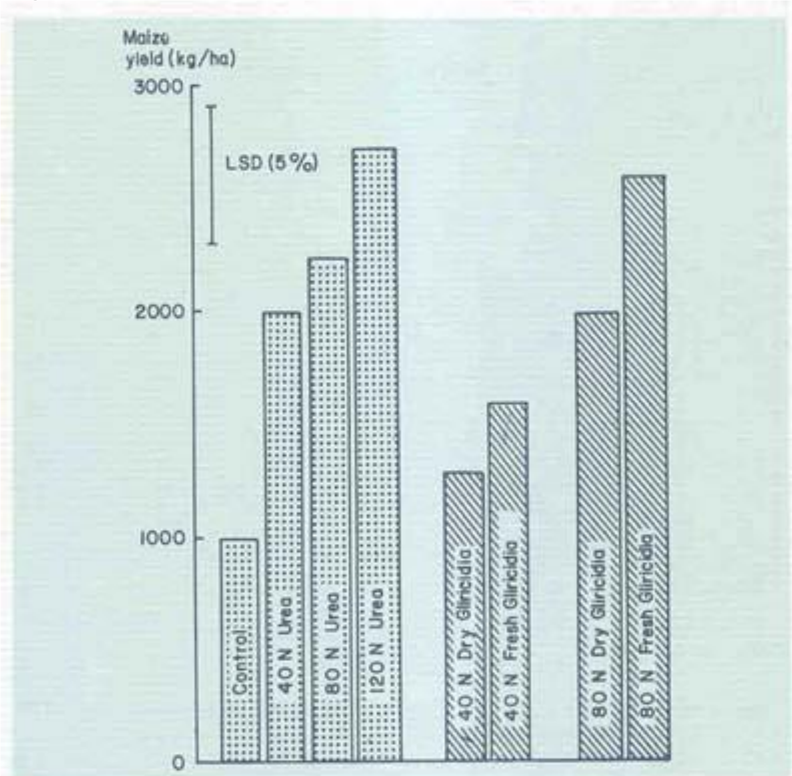
Alley farming

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).

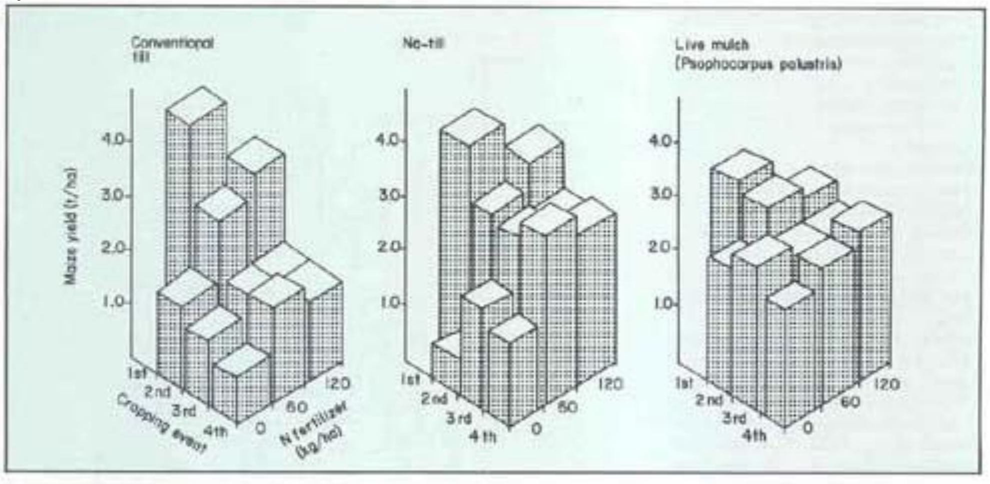
Yamoah et al (1984) observed that prunings from *Gliricidia, Flemingia* and *Cassia* applied before planting maize decomposed by 96%, 58% and 46% respectively during the course of the season, and released the equivalent of 252, 70 and 120 kg N/ha. However, maize grain yield increased by only 15% for *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*.*

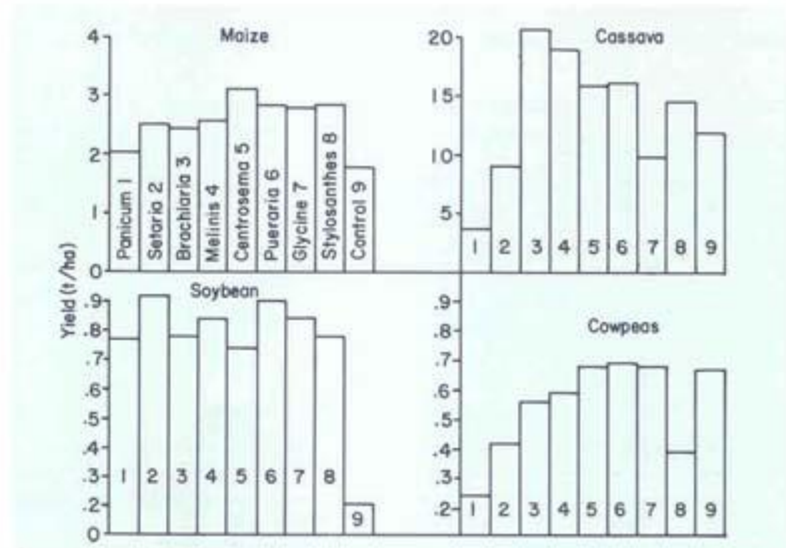


[*] In the first season a blanket application of compound fertilizer (60 kg N/ha) was made. Plots then received 3 different rates of N.
Source: Akobundu (1980).

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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Evaluation of some *stylosanthes* accessions for subhumid conditions of Nigeria

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Summary

IT HAS ALWAYS *been difficult to find forage legumes with the production characteristics that can help maximise animal performance, and that are also adapted to the alternating wet and dry seasons of the subhumid zone of Africa. Among the characters in demand are drought tolerance, good herbage production and plant persistence, either through regeneration after burning or heavy grazing or through self-seeding. Ideally they should also provide a good quality, standing hay crop that will help sustain animals through the dry season .Another important attribute is disease resistance because the wet season usually provides conditions ideal for disease development and advancement.*

Stylosanthes spp. have many of the qualities demanded by African conditions but disease, in particular anthracnose, caused by the fungus Colletotrichum gloeosporoides, has restricted their use. One species, S. hamata cv Verano, a selection made by scientists from Australia's Commonwealth Scientific and Industrial Research Organisation, combines disease resistance with the other favourable agronomic characteristics. This species has been widely planted in the tropics and has the potential for even further spread. However, whether Verano's disease resistance will be maintained is uncertain; if new virulent strains of anthracnose arise, they could nullify all the advantages of Verano-based pasture improvement.

Because of this threat, ILCA scientists have screened a range of potentially useful Stylosanthes spp. that could either outperform, or substitute for Verano if its disease resistance breaks down. This paper gives details of their agronomic performance and disease resistance, and identifies four accessions that show promise for the subhumid zone.

Introduction

During the dry season in the subhumid zone of West Africa, the crude protein level of the largely grass pasture drops below 3% between October and April. This poor quality feed cannot meet animal needs and cattle lose weight and become anoestrous.

When the ILCA Subhumid Zone Programme commenced its research into ways of alleviating the dry-season feed quality problem, three *Stylosanthes* cultivars were recommended by the National Animal Production Research Institute (NAPRI), Shika, northern Nigeria. They were: *Stylosanthes guianensis* cv *Cook, S. guianensis* cv *Schofield* and *S. hamata* cv *Verano.* These cultivars had been selected from many, mainly Australian, varieties through years of screening at NAPRI (Agishi, pers. comm.). However, when these cultivars were grown by ILCA under subhumid conditions, characterised by a longer growing period and higher rainfall than at Shika, *S. guianensis* cv Schofield succumbed to serious attacks of anthracnose caused by *Colletotrichum gloeosporoides.* This fungal disease also occasionally affected *S. guianensis* cv *Cook* which is still being used in trials. *S. hamata* cv Verano has so far proved resistant to anthracnose.

Trials have indicated that *S. guianensis* cv Cook and *S. hamata* cv Verano can be used either by incorporating them into cereal crop mixtures or in the concentrated legume pastures used as fodder banks. However, given the threat posed by anthracnose, there is a danger in encouraging their wide adoption by pastoralists unless other legumes are identified as safe replacements for the two cultivars. With this objective a number of promising *Stylosanthes* entries within the species *S. capitata, S. guianensis* "tardio" and *S. macrocephala* were acquired from the Centro International de Agricultura Tropical (CIAT), Columbia. This report summarises 2 years of measurements and observation made on these accessions at the research sites of ILCA's Subhumid Zone Programme.

Material and methods

Two-gram seed samples of the 17 *Stylosanthes* entries, scarified by immersion in concentrated $H_2 S0_4$ and treated with a Difolatan and Malathion mixture, were received from the Tropical Pastures Programme of CIAT in June 1982. One hundred seeds of each entry were sown on 19 June 1982 in trays filled with surface soil. None of these seeds were inoculated. After 4 weeks, 30 seedlings of each entry were transplanted into 1 x 1 m plots replicated three times. The soil of the experimental area is of the ferruginous type, with a sandy surface underlain by a weakly developed clay and a mottled and concretionary subsoil. The plots were fertilized with single superphosphate at the rate of 200 kg/ha in the first year, followed by a dressing of 100 kg in the second year. The plots were weeded by hand.

In the first year observations were made only on the incidence of disease symptoms and date of flowering. In the second year the plots were uniformly cut at a height of 6 cm above ground in the last week of April. Regeneration of the various entries occurred from cut stems and also from free seeds except in the case of *S. guianensis* "tardio" which does not produce seeds.

Observations on flowering and anthracnose were made during the growing season, and the dry matter available at the season's end (November) was determined by sampling one 0.25 m^2 quadrat from each replicate. Leaf retention during the dry season was scored visually and seeds were collected at the appropriate time by sampling another 0.25 m^2 quadrat from each plot.

In November 1983, topsoil (0–15 cm) from each plot was sampled by removing five 6 cm cores. Composite samples were prepared and analysed for organic matter and total nitrogen. Five kilograms of the composited soil under each entry was split into five 1 kg lots and 10 seedlings of maize were grown in each of these for 6 weeks. The total dry weight of the seedlings was determined after washing the plants free of sand under slow-running water and drying at 60°C. The dried seedlings, and more mature samples collected in December, were ground and analysed for total N. The soil and plant analyses were done at the Service Laboratory of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.

Results and discussion

Inter- and intra-specific differences in dry matter and quality of legumes at the end of the growing season are given in Table 1. All three "tardio" entries yielded more than 7 t/ha and had a high crude protein content (CP). *Stylosanthes capitata* 1019 and 1315 were comparable to the "tardio" entries in quality at the time of sampling. All the *S. macrocephala* entries had less than 5% CP.

Low quality during the dry season may be a function of the percentage leaf retention. *S. macrocephala* dropped all leaves in the dry season while the "tardio" entries retained most of them. There was little evidence of anthracnose in most of the entries except *S. capitata* 1693 and 1405 where lesions were moderately prevalent (Table 1).

Table 1. *Relative performance of Stylosanthes accessions in the subhumid zone of Nigeria*.

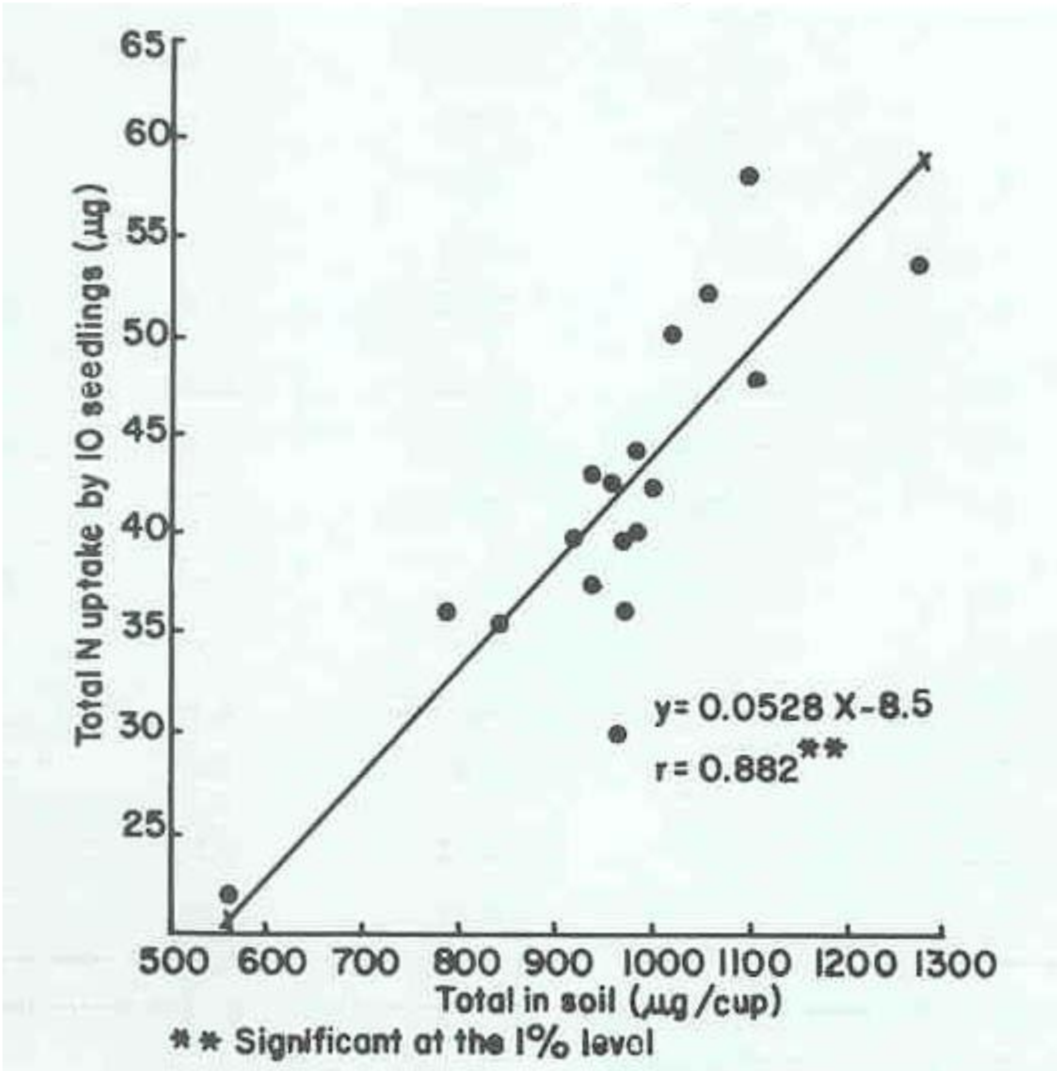
Species	CIAT acc. no.	Anthrac-nose rating[a]	Dry-season leaf retention index[b]	Date of flowering	Total DM available (kg/ha)	CP in Dec. (% DM)	Seed yield (kg/ha)
S. capitata	1019	1	3.0	Oct.	4175	9.81	40
	1342	1	3.5	Oct.	3748	5.79	131
	1405	3	2.5	Aug.	3712	6.17	49
	1693	3	3.0	Aug.	3450	5.68	182
	1315	1	2.5	Oct.	3444	8.76	157
	2044	1	2.5	Oct.	3432	4.38	80
	1097	1	2.0	Aug.	3315	5.82	84
	1728	1	5	Oct.	3240	4.15	61
	1318	1	2.5	Oct.	2730	5.56	157
	1441	1	2.5	Oct.	2505	4.19	34
S. guianensis "tardio"	1283	1	5.0	Nov./Dec.	7612	8.44	–
	1280	1	5.0	Nov./Dec.	7583	8.98	–
	1523		5.0	Nov./Dec.	7066	11.78	–
S.macrocephala	2039	2	1.0	Jul./Aug.	4894	4.74	115
	1582	2	1.0	Jul./Aug.	3800	4.88	175
	2133	2	1.0	Jul./Aug.	3669	4.59	96
	1643	2	1.0	Jul./Aug.	3269	4.79	77
Mean		1.47	2.67		4212	6.38	103
S.D		0.72	34		1620	2.29	51

[a] Anthracnose rating: *5* = *lesions* in plants very prevalent with leaf drop; *3* = *lesions* moderately prevalent with no leaf drop;1= no apparent lesions.
[b] Leaf retention index: *5* = no leaf drop; *4* = *25%* leaf drop; *3* = *50%* leaf drop; *2* = *75%* leaf drop; 1 = all leaves dropped.

Soil analysis and bioassay carried out on soil samples taken from under each *Stylosanthes* entry showed that maize growth was directly correlated with soil N (Table 2 and Figure 1). However, the proportion of N utilised by the maize from each soil sample did not vary much and ranged between 4 and 5% of the total N. Dry matter accumulation in maize grown in soils collected under the various legumes was significantly higher than in maize grown in soils that were dominated by natural grasses. Differences in both organic C and N contents between the `legume' and `no-legume' soils may explain the variability in maize growth.

Table 2. *Properties of soil under legumes and bioassay of N uptake by maize*.

Species	Soil				Bioassay		
	CIAT acc. no.	% C	% N	Total N (µg/cup)	Dry weight (g)	% N	Total N (µg)
S. capitata	1019	1.22	0.111	1110	6.77	0.839	58.4
	1342	1.27	0.102	1020	6.38	0.786	50.1
	1405	1.00	0.096	960	6.30	0.675	42.5
	1693	1.03	0.100	1000	6.30	0.675	42.5
	1315	1.06	0.097	970	6.14	0.636	39.1
	2044	0.93	0.098	980	6.12	0.645	40.0
	1097	0.95	0.092	920	6.02	0.659	39.6
	1728	0.96	0.094	940	5.94	0.632	37.5
	1318	0.89	0.097	970	5.92	0.612	36.2
	1441	0.95	0.078	780	5.50	0.657	36.1
S. guianensis"tardio"	1523	1.18	0.128	1280	6.36	0.886	56.3
	1280	1.38	0.099	990	6.08	0.727	44.2
	1283	0.93	0.084	840	4.66	0.765	35.6
S macrocephala	2039	1.19	0.106	1060	6.74	0.776	53.3
	1582	1.43	0.101	1010	6.68	0.723	43.3
	2133	1.04	0.094	940	6.14	0.700	42.9
	1643	1.01	0.096	960	5.20	0.676	35.2
No legume		0.56	0.056	560	3.50	0.641	22.4
Mean		1.04	0.096	960	5.94	0.706	40.01
S.D.		0.202	0.014	263	0.817	0.077	12.47



The results suggest that there are entries within each species that benefit subsequent crops (Table 2). For example, soil under entries 1019 and 1342 of *S. capitata,* 1523 of "tardio", and 2039 and 1582 of *S. macrocephala* ranked high in both C and N. The potential value of this has been demonstrated by experiments conducted at Kurmin Biri, one of the ILCA Subhumid Zone Programme's case study areas, where significantly higher maize yields were achieved on soils where *S. guianensis* cv Cook has been grown for 2 years and *S. hamata* cv Verano for 3 years.

Hence the potential contribution to soil fertility may become an important selection criterion for legumes in those agropastoral systems where the practice of bush fallowing to restore soil fertility is shortened due to increasing crop production, or where farmers lease land to pastoralists for fodder production. Bioassays are a useful and rapid technique for estimating relative N accruals in soils under legumes, especially when large numbers of accessions are handled in field programmes where laboratory facilities are minimal.

For a forage legume to be successful in the agropastoral production systems of the subhumid zone of Nigeria, it needs a number of attributes, including drought tolerance, high productivity, good quality, ability to transfer N to soil and to regenerate after grazing or burning. It is extremely difficult to identify a plant which combines all these, and a balance of desirable traits to suit each particular environment will need to be selected.

Both *S. guianensis* "tardio" and *S. macrocephala* have disadvantages. Although they flowered, the *S. guianensis* accessions did not set seed in either year. This is a severe handicap in pastoral areas where overgrazing and accidental fire can impede vegetative regeneration. *S. macrocephala* is of low value during the dry season because of its low leaf retention. *S. capitata* offers more encouragement. Entries 1019, 1342,1693 and 1315 have a good balance of characteristics, including disease resistance, feed quality, drought tolerance, good dry matter and seed production, persistence and N transfer to the soil. They have therefore been selected for further trials and fresh accessions are continuing to be evaluated.

A review of integrated surveys for resource inventory and monitoring of pastoral production systems in sub-Saharan Africa*

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Summary

MANY GROUPS *are interested in assessing and monitoring large-scale changes across the ecological zones of the African continent through satellites or aerial surveys. Land use planners, economists and national and international agencies engaged in pest control, disaster relief and agricultural production, can all make effective use of this information. However such information has to have a firm basis, and this can only be built from a systematic and sophisticated data collection that relates what the aerial survey or satellite sees to the 'ground truth'.*

Building effective databases in sub-Saharan Africa has been hindered by problems of cost, logistics, methodological inadequacies and the sheer size of the venture. ILCA made an early commitment to data collection, viewing the basic information as a resource that would assist the various research programmes in analysing and identifying problems and would serve as a measure of progress.

The authors have considerable experience in data collection and analysis. In this paper they draw upon their experience and review the various approaches and techniques used in a number of African countries and suggest ways to build more effective data bases.

Introduction

Development efforts should be predicated on the rational use and management of a region's natural resources. Only in this way will improvements in human welfare be sustained. Collection and analysis of data on pastoral production systems in sub-Saharan Africa provides the basis for such sound development.

An effective database should provide details of the relationship between livestock, water resources and rangelands, coupled with studies of livestock management and production. Analyses of human labour resources, and household income and expenditure are other important parts. Relating the spectral signatures of soil, water and vegetation, as observed from satellites, provides a regional, even continental, inventory of vegetation and water resources. But such broad-scale imagery must be refined even further through the use of systematic aerial surveys and ground-level studies.

The problem

Of the 12 million km^2 of sub-Saharan Africa over half has an arid or semi-arid climate, where extensive grazing is the major form of land use. These pastoral lands are inhabited by nearly 40 million people who own around 80 million tropical livestock units (TLU), or about 57% of the total ruminant livestock population of Africa.

Sub-Saharan Africa gained wide publicity through the droughts that devastated the region from the late 1960s on. These droughts brought into sharp focus the fragility of the pastoral ecosystems and the problems facing the people they support. This awareness coupled with the political and strategic importance of the region attracted substantial international aid. Between 1965 and 1980 more than US$ 650 million has been spent solely on livestock development projects. Unfortunately, in retrospect most of the projects are now considered to be failures. The major cause of these many failures was that development proceeded without the benefit of a sound knowledge base, Eicher and Baker (1982) noting that "Research on the behaviour of livestock herders in Africa is about at the same point where research was on crop production some 20 years ago—many assertions and a sparse supply of facts".

This lack of knowledge is exacerbated by the complexity of African pastoral production systems. Apart from providing subsistence food (milk and meat) and cash for household needs, livestock are used for transport and tillage, and also have important social functions both as status markers and in the maintenance of social ties.

In the pastoral areas the grazing land is recognized as a public resource available to all stockowners, yet animals are privately owned. Because of the generally free access to grazing land, many pastoralist societies have responded to the seasonal fluctuations in grazing and water resources by adopting a nomadic or semi-nomadic lifestyle. They have acquired an intimate knowledge of environmental conditions as well as great skills in managing their animals.

More so than farmers, they are exposed to short-term hazards—such as animal disease, scarcity of water, and fires—and to longer cycles of 'boom and bust' when drought follows a run of good seasons. Their way of life is threatened by communal overgrazing of their rangelands and the encroachment of sedentary farming into marginal croplands.

Techniques and their application

Observations can be made at three levels (space, air and ground) and the best combination must be found between low-cost techniques of extensive data collection (space, air) and intensive data collection by ground teams.

Triple-tiered techniques have been developed to support range management of the semi-arid rangelands in Australia through the Land-Image-Based Geographic Information System (LIBGRIS). Spatial data sets including land systems, erosional features and land tenure, are used to monitor biomass cover and greenness, and to predict carrying capacity and flooding. Sophisticated computer data processing and digital analysis together with modelling, e.g. vegetation/Landsat response, rainfall/runoff, are increasingly employed (Graetz et al, 1982).

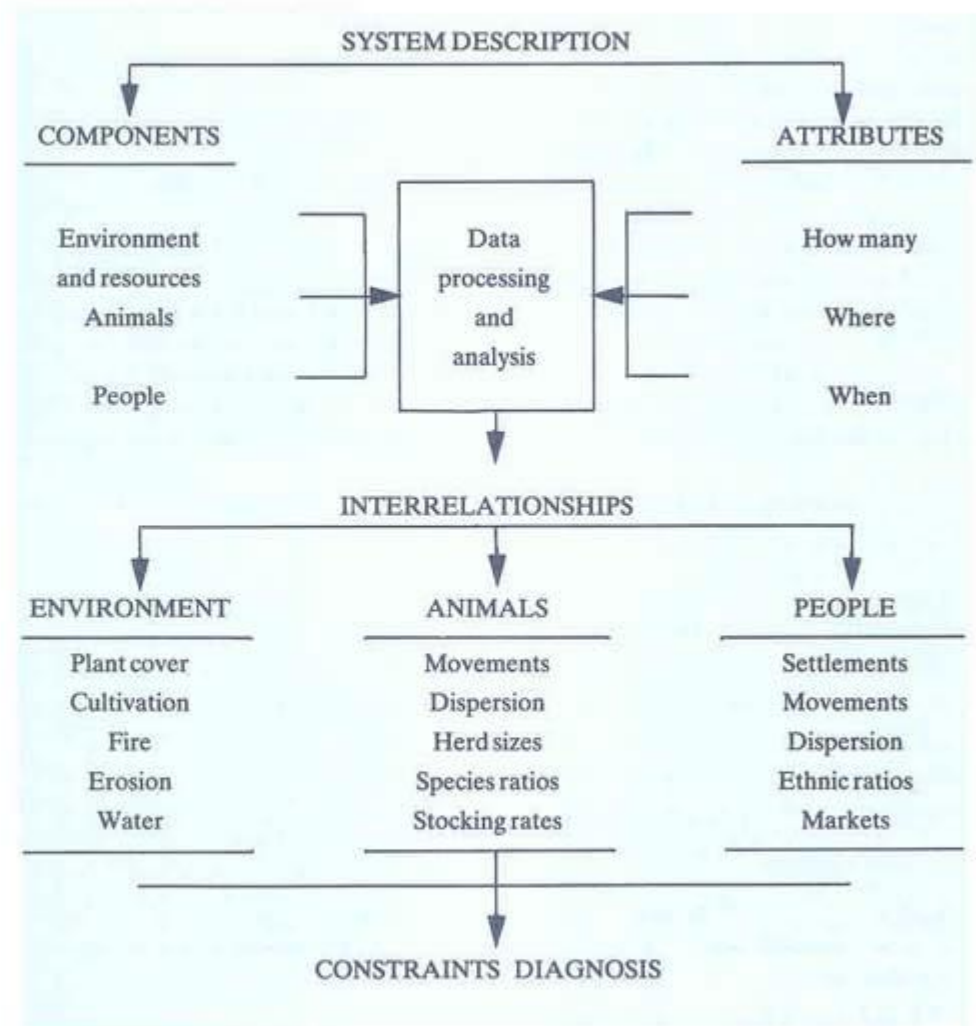
Satellite imagery—in particular the NOAA satellites—has been used to classify land cover, the resulting map corresponding well with existing vegetation maps (Tucker et al, 1984). Plant growth during such crises as the 1982 drought in East Africa and similar events in 1983 in the Sahel was also monitored (Tucker et al, 1984).

Large-scale remote monitoring has been carried out by FAO in arid areas (50–200mm) prone to the ravages of the desert locust. Landsat provided the systematic landscape mapping of potential desert locust habitats over 11 million km^2 while Meteosat identified soil moisture conditions through rainfall assessment, this assessment being aided by green-leaf density estimates from NOAA. Computer transformation of the raw satellite data into manageable information provided a powerful tool for improved forecasting and timely coordination of field operations (Hielkema,1983).

The second tier of data collection is carried out by small aircraft at low altitude. The methods used to count animals and assess ecological conditions were originally developed in East Africa for wildlife management in national parks (Norton-Griffiths, 1978; Croze and Gwynne, 1981). More recently, systematic reconnaissance flights (SRF) have been adapted to conduct inventories and monitor the seasonal distribution patterns of livestock and people in the pastoral and agropastoral regions of Africa (Milligan and de Leeuw, 1983).

The SRF technique usually consists of a descriptive phase followed by a preliminary analysis to discover interrelationships among the various data sets. This then leads on to a diagnosis of constraints within the production system under study (Figure 1).

Figure 1. *Data generation from systematic reconnaissance flights.*



During 1981–83 surveys were carried out jointly by UNEP and FAO in Senegal and by ILCA in Mali, Niger, Nigeria and Ethiopia. They have also become an integral part of surveys for project feasibility studies, such as for the construction of the Jonglei canal in the Sudan (S. Cobb, pers. comm.).

Senegal

Systematic integration of different monitoring techniques has been employed in the Sahel region of Senegal (Vanpraet, 1983). After the initial stratification of the region using Landsat data and existing vegetation maps, reflectance measurements by the NOAA satellite were used to generate wet season biomass growth patterns which were validated through extensive ground sampling on 120 sites. Gaston et al (1983) reported that the "normalized-difference vegetation index" (Tucker et al, 1984) gave green biomass estimates in classes of 200 kg dry matter per ha, which were used to provide end-of-season forage forecasts for a region of 30 000 km.[2.] Since quantitative seasonal livestock distributions were already known from low-altitude aerial surveys, the overall dry-season forage situation was predicted for the period 1981–83.

Consequently, rapid data processing made it possible to warn Senegalese government agencies in early October 1983 that the range grazing resources generated by the summer rains were only 10 and 30% of those estimated in 1981 and 1982 respectively, thus predicting serious forage shortages during the 1983/84 dry season.

Mali

Several aerial surveys were undertaken to support ILCA livestock systems research projects in Mali. The Niger floodplain, which covers 17 000 km^2 and is of crucial importance to the Malian economy, was overflown three times to assess livestock distribution. During the dry season (November to June) this floodplain supports up to 1.2 million cattle and 0.5 million smallstock, attracted by the perennial floodplain grassland and the permanent water sources in the area (Milligan et al, 1982). Pastoralism and rice cropping in the lower parts, and cereal cropping in the higher parts of the floodplain and the surrounding semi-arid uplands have led to complex land-use patterns and to conflicts between user groups (Table 1).

Table 1. *Seasonal cattle distribution and environmental conditions in four management strata in the Niger floodplain in Mali,1980–1982*.

Land management strata	Area (km^2)	Cattle population ('000)			Environment[a]		
		Oct	March	June	Flooded	Rice (% of area)	Cereals
Upland Sahel	13 200	226	63	116	0	0	19
Transition zone	5 810	237	91	102	10	7	14
Elevated plains	5 820	230	189	181	21	12	9
Inundated plains	11 120	114	871	410	72	24	3
Total	35 950	807	1214	809	27	10	12

[a] October 1980.
Adapted from: Milligan and de Leeuw (1983).

Low-level aerial surveys coupled with intensive ground surveys have been undertaken to elucidate the relationships between transhumance movements and their underlying causes (water and range resources, trade, dry-season tillage by oxen etc.). Subsequent analyses are aimed at identifying areas of seasonal overstocking and understocking through the comparison of SRF stocking densities with the dry-season productivity of the major vegetation types (Hiernaux and Diarra,1984). In the longer term this database is expected to assist in the development of a balanced land-use plan for the entire region, as proposed by the World Bank and Malian development agencies.

Niger

In the pastoral zone of the Niger Republic, SRF were carried out to provide background data for an integrated USAID development project (Aronson, 1982). As in Mali, secondary information was combined with SRF data to stratify the 80 000 km^2 project area into ‘management units’, on the supposition that the identification of practical interventions requires geographically distinct and homogeneous units.

The aerial inventories recorded a target population of 170 000 pastoralists who owned 330 000 cattle, 1 million smallstock and 100 000 camels (Milligan, 1982). The average stocking density ranged from 13 to 31 ha per TLU, depending on season and location (Table 2).

Table 2. *Seasonal livestock densities in the pastoral zone of the Niger Republic, 1981–82 (numbers/km^2).*

	Cattle	Smallstock	Camels	Donkeys	Total TLU[a]	Ha/TLU
Northern part						
Wet season	1.5	6.5	2.5	0.4	4.8	20
Dry season	1.1	6.7	1.2	0.2	3.2	31
Southern part						
Wet season	6.4	10.2	0.6	0.3	7.1	14
Dry season	5.5	13.6	1.3	0.4	7.7	13

[a] TLU = Tropical livestock unit = 250 kg liveweight: cattle = 0.75; smallstock = 0.15; camels = 1.0; donkeys = 0.50 TLU.
Adapted from: Milligan (1982).

Simultaneous rapid ground surveys covering animal productivity, water resource utilisation, labour use, human health and nutrition, revealed a complex set of constraints: low animal productivity, herd sizes too small for household subsistence needs, and extreme human and animal stress during the later part (April to July) of the dry season (Wilson and Wagenaar, 1983; Aronson, 1982; de Leeuw, 1983). The development plan proposed intervention strategies for reducing these constraints (de Leeuw and de Haan, 1983).

Nigeria

In Nigeria SRFs were prompted by the need to define the target area of ILCA's research in the subhumid zone (ILCA, 1979; 1982). Although there is a large body of information on soils, vegetation and land use for this zone, census data on livestock are inaccurate and out of date, while livestock distribution is uncertain (ILCA, 1979). Southward shifts in traditional transhumance movements, due to the 1969–974 drought as well as the reduction in tsetse challenge and increased sedentarisation of pastoralists, were inferred from data of earlier censuses and large-scale vaccination campaigns against rinderpest (Fricke, 1979). These trends were confirmed by aerial surveys in selected areas (Milligan et al, 1979) and by intensive studies on the impact of tsetse eradication schemes (Bourne and Milligan, 1983).

The rapid change from pastoral to sedentary land use followed improvements to the communication network, infrastructure development and the increased food demands of a growing urban population. To pinpoint these changes and to update the existing database, about 350 000 km 2 of the zone were flown along transects at 50 km spacing. In this manner the vegetation physiognomy, land use and settlement, infrastructure and livestock were recorded or counted in the dry and wet season of 1982 (Bourne and Milligan, 1983).

A preliminary analysis of the low-intensity flight data indicated a closer association of cropping intensity and livestock than expected. The wet-season and dry-season populations in the subhumid zone have become almost equal, amounting to 4.3 and 4.7 million cattle respectively or about half the total estimated Nigerian cattle population.

During these surveys it became clear that the visual recording of complex landuse patterns and their associated crop mixtures posed problems, and that the complementary use of automated vertical colour photography could become a powerful tool in the quantification of land-use parameters in farming systems. Similar techniques have been successfully used by Ecosystems (1982) during SRF surveys in the Machakos district of Kenya.

Integrated techniques

Although aerial surveys are now recognized as an inexpensive data collection method over large areas, multistage data collection needs further experimentation and testing. It was shown above that integration of techniques differed between projects, with a general reliance on SRF and variable use of satellite imagery and ground survey techniques. In several projects data collection was not planned in advance, and often pastoral household studies had proceeded without an adequate appreciation of the pastoralist's distribution of resources, wealth and other variables. It would be more logical if aerial surveys were used to guide the sampling design of ground investigations (Milligan and de Leeuw, 1983). An integrated technique would use data from satellite imagery to pinpoint areas for aerial survey, and aerial surveys, by providing information on such things as herd movements, would in turn guide the movements of ground teams. In effect, the three tiers should be integrated in both time and space.

To investigate the improved use of SRF for such goals, two ILCA pilot projects were started in the arid Ghourma region of Mali, and in the Maasai systems study area in semi-arid Kenya (ILCA, 1982). In the Ghourma, 83 000 km^2 were overflown twice in 1983 while multidisciplinary teams conducted rapid interviews of selected households on cattle and smallstock productivity, disease incidence, water and grazing resources and movement patterns (ILCA,1982). In Kenya during 1981–1983, intensive enquiries were made into the Maasai pastoral economy. These studies included surveys of herd and resource management practices, milk and livestock offtake, labour budgets, and income and expenditure in a sample of 90 households randomly stratified according to a livestock/people "wealth" ratio (Bekure,1983; Grandin, 1983; Semenye and de Leeuw, 1984). The contribution of SRF to this intensive systems study is being assessed and 'rapid appraisal methods' are being developed to describe (agro-) pastoral production systems similar to those promoted and effectively used by the farming systems research teams of the crop-oriented international research centres (Byerlee and Collinson,1980).

Future developments

It is expected that in the near future rapid improvements in satellite technology coupled with more efficient data processing, digital analysis and mapping as well as the use of modelling techniques will encourage wider application of remote-sensed data to studies of the pastoral areas of sub-Saharan Africa (Hielkema, 1983; Tucker et al, 1984). Increased use of multitemporal data from satellites (NOAA, Meteosat, Landsat, SPOT) with different levels of resolution (and consequently different costs of imagery) will result in better definition of reflectance signatures of complex vegetation and land-use patterns.

Further integration of such remote-sensed data into overall three-tiered inventory and monitoring systems will improve forecasting of environmental change and of drought, and will help develop early warning procedures and preventive or remedial actions (Vanpraet, 1983; de Leeuw and de Haan, 1983).

Such forecasting procedures could be verified against current local information now that communication systems are becoming increasingly efficient in rural Africa. The same applies to meteorological networks, the distribution of which is notoriously inadequate. Interpolation of spatially and temporally scattered rainfall data with remote-sensed green biomass estimates would help in predictions of crop yields and range resources.

These improvements in multilevel and multidisciplinary inventory and monitoring systems will greatly assist in the more effective planning of long-term strategies for land-use development in the pastoral regions of sub-Saharan Africa.

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Pastoralism and milk production*

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Summary

THE SUCCESS *of the African pastoral family is determined by the amount of milk their animals yield. These animals, like their masters, are adapted to an often harsh environment, in which hardiness and the ability to survive are more important than high milk yields. However, the milk yield is still susceptible to seasonal influences and during the dry season there is often considerable competition between calf and man for the declining production. The calf usually suffers, with the result that the breeding rate and ultimate productivity of the herd is reduced, because a malnourished female calf is slow to reach reproductive age. Milk production in the pastoral system, and the few opportunities for its improvement, are discussed in this article.*

Introduction

Pastoralism has evolved in drier regions on land that is either unsuited to cultivation or where cropping is a marginal and precarious enterprise. In Africa pastoralists range across the climatic zones, being found in the subhumid zone of Nigeria (1300–1500 mm rainfall) right through to the arid zone of northern Kenya (150–400 mm rainfall). The mainstay of pastoralism is milk production from cattle, camels, goats and sheep; utilisation of milk from horses and donkeys is uncommon. Meat, a less efficiently produced commodity, is normally eaten only on festive occasions or during severe food shortages. Pastoralists may be nomadic, transhumant or quasisedentary; cultivation is a new but increasingly common enterprise.

Historically, the colonial powers paid little attention to pastoralists. The areas used were of low potential, their way of life inherently subsistent, and their contribution to development negligible. Contact was slight and sometimes centred on the removal of pastoralists from potential ranching land to even more marginal areas.

The first scientific group to take a positive interest in pastoralists were the social anthropologists. Only recently have animal scientists begun recording milk and animal performance. This interest in milk production is part of the broader objective of increasing animal production by improving either the utilisation of the rangelands or the animal husbandry practices.

Pastoralism has certain unique characteristics. First, milk and milk products are the mainstay of the human diet and at times the very survival of the household hinges on their continued production. Second, since supplementation of cows is uncommon, milk production is a function of season rather than stage of lactation. Third, since nutritional levels are low and water may be restricted, the ability to produce milk under nutritional stress and to survive adverse climatic conditions may be more important than high yields. Finally, owing to the crucial role of milk in the pastoralist diet and society, a delicate balance must be struck between milk offtake for human needs and milk intake by the calf since the calf has no access to either milk substitutes or supplements. While camels and smallstock play an important role in certain societies the following general description of pastoralist milk production will concentrate on cattle.

Milk yield and milk offtake

In high-yielding *Bos taurus* animals milk offtake (i.e. milk not consumed by the calf) is a reliable indicator of total milk yield since let-down and retention problems are rare. In contrast, the pastoralists' cattle are usually *B. indicus* and will not readily let down their milk without the stimulus of their calf, and it is difficult to strip out all the milk by hand. Milk offtake in pastoral cattle is only about 30% of the yield during the first 4 months of the lactation, increasing in proportion as the calf develops a functional rumen. This total yield must be estimated by adding measured milk offtake by humans to estimated milk intake by calves, this latter term introducing a significant source of error into the final estimate.

Estimated total milk yields vary between 430 kg over 6 months in White Fulani to 300 kg in Maasai cattle over 10 months (Table 1), equivalent to 2.4 and 2.7 kg.day^{1} respectively. Ethiopian Boran cows give a mean yield of 680 kg over a lactation of 7 months although the long lactations in the Borana system of southern Ethiopia yield an estimated 750 kg. The lower estimate of 518 kg over 7 months for Boran in Kenya (McKay, 1957) may be due to the drier environment.

Table 1. *Estimated lactation yield (kg) of Zebu cattle under pastoral conditions*.

Breed	Yield per cow (kg)	Recording period (months)	Source
White Fulani (Nigeria)	535	6	Otchere (unpubl.)
Maasai (Kenya)	800	10	Semenye and de Leeuw (in press)
Delta Fulani (Mali)	430	6	Diallo et al (1981)
Boran (Ethiopia)	680	7	Nicholson (unpubl.)
Boran (Kenya)	518	7	McKay (1957)

The most objective method of determining milk yield would be the weekly administration of oxytocin to allow complete milking out. Unfortunately pastoralists generally reject any experimental method that interferes with the normal milking procedure. An alternative is 'before and after' weighing of calves; this technique using dial scales with calf slings has produced disappointing results because intake is so low that the change in weight cannot be measured accurately enough. Working with more sensitive beam scales, intake can be measured to ±50 g but the process is laborious and the equipment expensive. Other workers have relied on the conversion factors of Drewry et al (1959) and Montsma (1960). More elaborate estimates may be obtained from the mathematical models of Konandreas and Anderson (1982) and equations based on calf growth and metabolizable energy content of the milk (Nicholson, 1984), but no great improvement has yet been demonstrated.

What becomes apparent is that individual and seasonal variations give rise to large standard errors of estimated mean yields. Most workers have found that year of calving and season of birth significantly affect both total milk offtake and total yield, while daily offtake and yield are a function of season, stage of lactation, lactation number and location (probably due to the human demand for milk varying with population). Total yield is also higher when calving occurs around the start of the main rainy season, indicating that better nutrition is elevating the normal yield peak in the first 2 or 3 months of lactation.

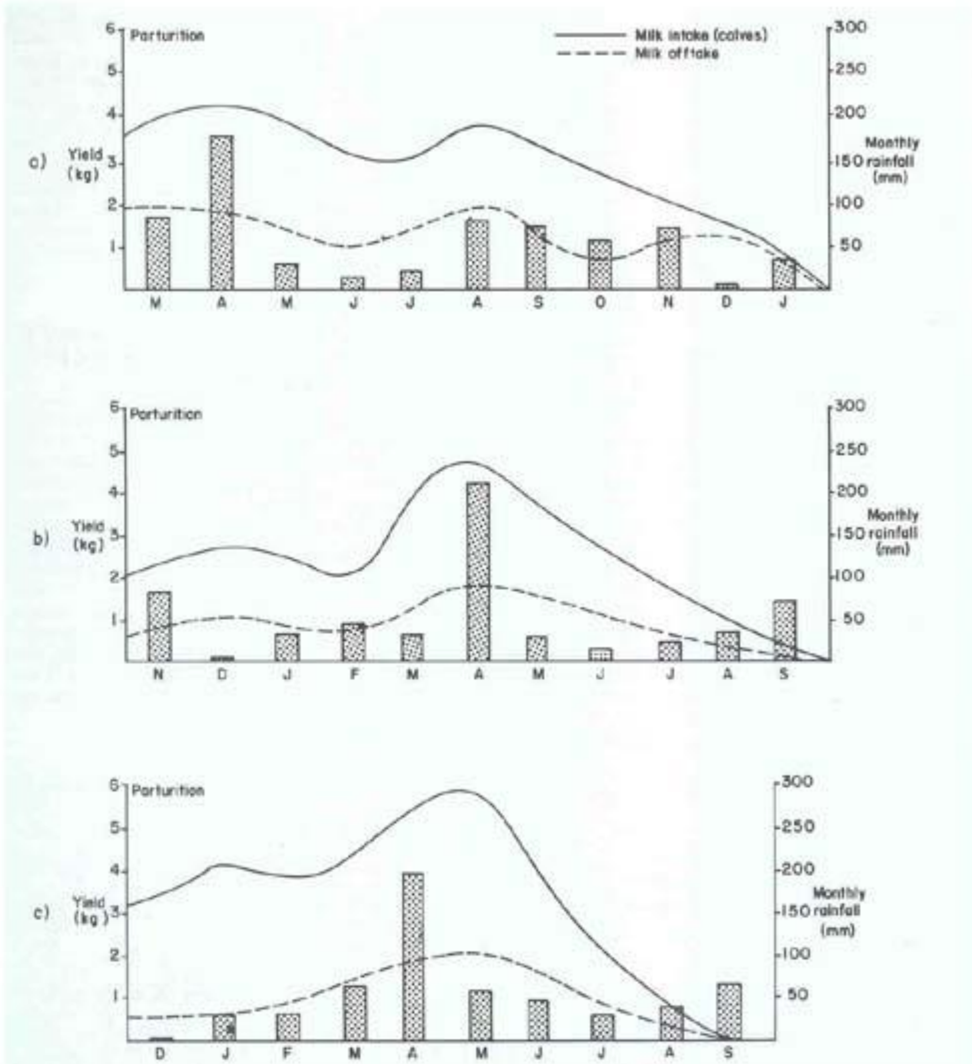
Hand-milking can be done before cattle leave their night enclosures and again on their return in the evening. This system is followed by the Borana and the Maasai pastoralists while the White Fulani cattle in Nigeria are milked only in the morning (Otchere, 1982). The Fulani tribe in Mali milk their animals in the evening and the calves remain with their dams through the night (Diallo et al,1981), whereas the Borana keep calves in their houses for a year or more and allow suckling twice a day and access to grazing during the daytime. Camels are milked several times a day by the Gabbra of southern Ethiopia, and apparently the camel calf is not essential to initiate letdown. Let-down in the absence of the calf is very difficult to induce in *B. indicus* cows, but the Borana have been observed to skin a dead calf and allow the dam to sniff the skin during milking, and by these means achieve a degree of let-down for several weeks.

Offtake is reported as 20–25% (Semenye and de Leeuw, in press), 25% (Otchere, unpubl.), 25–38% (Nicholson, unpubl.) and 31% (Diallo et al, 1981) of total milk yield. The offtake/intake ratio appears to be fairly constant for the first 4 months irrespective of yield. Actual offtake varies enormously from 150 ml per day in the dry season to 3 1 or more per day from highyielding cows during the rains. Mean offtake in Borana villages is 312 kg, with a standard deviation of ±108 kg reflecting the wide variation (Nicholson, unpubl.). This figure is similar to the 235 kg recorded in Mali (Diallo et al, 1981) and 286 kg over 416 days in Nigerian Fulani (Otchere, unpubl.).

The lactation curve

The classic lactation curve of well nourished commercial dairy cattle is not seen in pastoralist cows because the major influence on production is the season. New grass following the onset of the rains causes a rapid rise in milk production at almost any stage of lactation while the dry season severely depresses milk yield. Figure 1a depicts a typical bimodal lactation curve for Boran cows calving just before the start of the 'main' (April/May) rains in southern Ethiopia. Figure 1b demonstrates that when these 'main' rains occur in the middle of the lactation, the second peak can surpass the first, while a cow calving in the dry season can reach peak yield as late as the sixth month of lactation (Figure 1c). Calf suckling during this period is vigorous and prolonged and 'before and after' weighing shows large intakes of up to 3.5 kg. The peak of the curve may not necessarily indicate final yield since the length of the rainy season, the severity of the dry season and the highly variable lactation length will thwart any such prediction. A lactation curve with three distinct peaks has been noted by the author in a 13-month lactation.

Figure 1. *Lactation curves of Boran cows under pastoralist conditions.*



Milk composition

The reluctance of pastoralists to allow complete hand-milking-out of their animals means that data on composition relate only to that fraction of the milk which is taken for human consumption. Borana milk showed large variations which were not consistently related to stage of lactation, to individual cows or to season (Dessalegne, pers. comm.). Total solids averaged 14.5% and fat 5.4%, giving an approximate energy content of 3.47 MJ.kg[1] (Tyrell and Reid, 1965). These data are. comparable with those of Orr and Gilks (1931), working with Maasai cattle, who reported solids as 14.8% and fat as 5.5%.

Seasonal variations in composition exist but authors do not agree. Dahl and Hjort (1976) cite Bartha who reported that fat percentage decreased in the dry season; Maliki (1981) states that wet-season milk is not considered to yield much butter. The Gurma Imrad and Delta Tuareg in Mali and the Borana consider the late rains and early dry season to give the richest milk (Wagenaar and Winter, pers. comm.; Nicholson, unpubl.). Composition affects the quality of milk products such as butter, soured milk and cheese, all of which may be prepared by pastoralists although cheese is less common.

Lactation length

Deliberate weaning is practised by some tribes. Wagenaar and Winter (pers. comm.) report that the Delta Fulani wean their calves at 11–12 months for the purpose of inducing oestrus in the cows. In contrast, Otchere (unpubl.) found that deliberate weaning was resorted to only when the dam was in an advanced state of pregnancy. Fulani herders smear dung on the teats to discourage the calf, while the pastoralists of the Accra plains tie a piece of rope to the calf's nose (Otchere, unpubl.) and the Somali tie a strip of thorn to the nose to inhibit suckling (Cossins, pers. comm.). In East Africa, natural weaning is normal in both Maasai (Semenye and de Leeuw, 1983) and Boran cattle. As a result lactation length is extremely variable (Table 2). Authors cited by Dahl and Hjort (1976) reported lactation lengths varying from 139 days in Kenya Boran to 12 months in Dinka cattle in Sudan. However, 7–9 months appears to be the average.

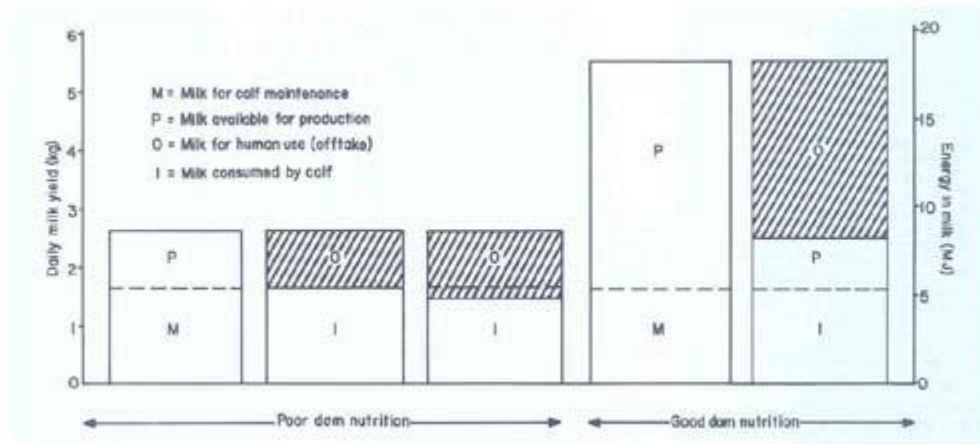
Table 2. *Variation in length of lactation (months)*.

Ethnic group	Typical lactation Length	Range	Source
Fulani (Nigeria)	13.9	–	Otchere (unpubl.)
Delta Fulani (Mali)	11.3	–	Diallo et al (1981)
Maasai (Kenya)	5	5–10	Semenye and de Leeuw (in press)
Borana (Ethiopia)	9.5	7–13.5	Nicholson (unpubl.)
Dinka (Sudan)	12	–	Dahl and Hjort (1976)
Somali (Somalia)	8	–	Mares (1954)
Borana (Kenya)	–	5.5–8	McKay (1957)

Calf growth

The relationship between calf growth and milk offtake is complex. If the offtake is high during periods of nutritional stress, the calf may even lose weight.

Figure 2. *Diagrammatic representation of the relationship between requirements for maintenance and production, and between intake and offtake.*



This is diagramatically represented in Figure 2 which shows how offtake can infringe upon the calf's maintenance needs. In the southern rangelands of Ethiopia, there are periods in the long dry season when calves lose weight and live off their body reserves. The owner, desperate for milk, tries to ensure that the calf does not die, which would terminate milk supply from the dam. Conversely, when the nutritional plane is high, offtake is also usually high but the calf still receives enough milk for reasonable weight gains. Diallo et al (1981) reported a positive correlation between milk offtake and calf growth, but any offtake means the calf will not realize its full potential. Typical weaning weights are shown in Table 3.

Table 3. *Calf weaning weights (kg) in various rangeland systems*.

Breed	Weight (kg)	Age (days)	System	Source
Boran (Kenya)	250	240	ranching	Nicholson (1984)
Boran(Ethiopia)	180	210	ranching	Abernossa ranch (Ethiopian Ministry of Agriculture)
Boran (Ethiopia)	47	210	pastoralist	Nicholson (1984)
Fulani (Nigeria)	55	180	pastoralist	Otchere (unpubl.)
Delta Fulani (Mali)	61	180	pastoralist	Diallo et al (1981)
Maasai (Kenya)	65	210	pastoralist	Semenye and de Leeuw (in press)

There is no doubt that milk offtake affects calf growth but it is difficult to assess by how much when there are other confounding factors such as water availability and frequency, disease, onset of rumen function and nutrition. The greatest difference is that between the Boran calves reared in the traditional way and Boran animals reared on an Ethiopian government ranch where all the milk goes to the calves. The 7-month weights average 47 and 180 kg respectively. The obvious superiority of the ranch animals is a reflection of their extra milk intake as well as the superior grazing and husbandry not usually encountered in pastoralist areas.

Potential calf growth in the absence of milk offtake can be predicted from actual growth and the metabolizable energy content of the milk provided milk offtake is known (Nicholson, 1984). Using such equations, it was predicted that, in a pastoralist system, Boran calves would be

120–140%a heavier at 8 months if they received all the available milk. While this is a somewhat academic consideration it does illustrate one of the most important constraints to animal productivity under pastoralist conditions.

Effect of milk production on reproductive rate

Milk offtake for human consumption and body adornment (several tribes adorn themselves with butter), combined with low milk yield, affects reproductive rate in two ways. First, milk offtake results in slower calf growth and late puberty and age at first calving, although this is probably exacerbated by post-weaning nutritional stress. Second, low reproduction rates, probably caused by lactational anoestrus, have been observed in Fulani cattle in Mali (Wagenaar and Winter, pers. comm.) and by Otchere (unpubl.) in the White Fulani breed in Nigeria. These observations may partly explain the long calving intervals of 15 months in the Borana system (Agrotec, 1974) and 27 months in the Fulani cattle of Nigeria (Otchere, unpubl.). Both estimates were based on only a short period of data collection and are probably underestimates. There are some suggestions that Zebu cattle are more prone to anoestrus than European cattle as a result of undernutrition during lactation and hormonal factors, but direct comparisons are not available.

Milk restriction may also contribute to calf mortality rates which vary from 9% in the Maasai (Semenye and de Leeuw, in press) to 49% in White Fulani in Nigeria (Otchere, unpubl.), and this further depresses annual cow productivity rates.

Milk from camels and smallstock

Pastoralists who rely on camels as a source of milk often live in harsher, drier environments than cattle pastoralists, but this is not always the case. The Gabbra of southern Ethiopia are mainly camel herders but share their habitat with the Borana, and the browsing habits of their camels seem to be complementary rather than competitive in terms of land use. Lactations vary between 12 and 18 months and offtake yields between 1000 and 2500 kg, although higher estimates have been reported (Dahl and Hjort, 1976). A feature of camel production is the high calf mortality, recorded as 65% in the Gabbra system and supported in the above review by Dahl and Hjort. Percentage of fat and total solids in milk is lower than in Zebu cattle and cattlemilk drinkers regard it as inferior. Average composition is 10.1% SNF and 2.9% fat (Williamson and Payne, 1978).

Both cattle and camel pastoralists complement their milk supply by keeping smallstock. Ethiopian Borana seldom drink sheep milk whereas goat milk is often used as a dry-season reserve, particularly for children. In Kenya the Turkana take milk from both sheep and goats while the Maasai, Samburu and Kenya Borana use only goat milk (Dahl and Hjort, 1976). These authors point out the difficulty of deciding whether quoted yields represent milk offtake for human use or total estimated yield. What is important to note is that milk from smallstock may be an important source of energy at certain times, and that goats and camels are able to exploit browse in the dry season better than cattle or sheep, and so continue to produce milk when cattle milk is scarce.

Conclusion

Milk production in pastoralist societies is marked by a strong seasonal influence on yield and composition. Because of poor nutrition milk production is correspondingly low and a significant part of the yield is taken for human use. As a result calf growth rates are poor and mortality is high. Poor nutritional status is therefore thought to be the main cause of delayed age at maturity and first calving. High-yielding cows are unsuited to such environments, and natural selection appears to have favoured the development of hardiness at the expense of high yields. Camels have higher yields and longer lactations than cows but the milk is of lower quality and not liked by all tribes. The milk of smallstock may be a crucial energy source in dry seasons, particularly for children, but is usually of secondary importance to that from cattle and camels.

It must be emphasised that pastoralists rely on milk as their staple food and that drought and seasonal stress are recurring facts of life. Pastoralists are efficient users of a difficult environment and opportunities for improvement are few. Three alternatives exist. The first is the introduction of a cropping enterprise which would allow diversification of the diet and provide stock with crop residues or forage as a source of feed during dry-season nutritional stress. The problem here is that in many pastoralist regions, cropping is not a viable option. Second, individual milk yields could be raised by a combination of supplementation and breeding, but the prospects for this are limited. Third, the ratio of people to milking cows could be lowered, but since the human population is increasing in Africa at present, and stock numbers are often at or beyond the carrying capacity of the ranges, this is unrealistic. Improvements in the system will be difficult to realize, and considerable thought must be given to the question of whether any change in pastoralism will not ultimately be for the worse.

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ILCA's computer facilities and their use*

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Summary

PROBLEMS RELATING *to availability, maintenance and servicing have restricted computer usage in sub-Saharan Africa. There is also the more fundamental issue of deciding what the computer is to do and how to keep the system flexible enough so that it can take on new functions and expand.*

ILCA began developing its computer system in 1980, and since then it has steadily expanded so that it is now one of the largest agricultural research computer networks in sub-Saharan Africa. In a sense it has been a pioneering effort, and this paper describes some of the problems encountered and provides useful information on computer networking and the potential of computers in livestock research.

It also describes the ILCA computer facility and the services which ILCA provides to national research organisations that do not have computer facilities to analyse the large volumes of data which have been collected over recent years.

Introduction

Since installing a Hewlett-Packard (HP) 3000 Series III computer in October 1980, the International Livestock Centre for Africa (ILCA) has been steadily expanding its computer capacity at headquarters and at its field stations. This expansion has involved Hewlett-Packard mini- and microcomputers. This paper outlines the growth of ILCA's computer network from 1980 to 1984, and discusses the usefulness and limitations of micro-computers using one of ILCA's research programmes outside Ethiopia as a case study. The paper concludes with a discussion of some problems in operating a micro-computer network.

ILCA'S computer system

The HP3000 was originally chosen in 1980 for ILCA's Information Services, but is now used by all departments within the Centre. Hewlett-Packard equipment was selected for the following reasons:

1. Hewlett-Packard equipment could be serviced within Ethiopia.

2. The International Development Research Centre (IDRC) had released MINISIS, a library database system compatible with the HP3000.

ILCA and the U.N. Economic Commission for Africa (ECA) bought from the Société d'Etudes de Réalisation Informatique et de Conseil (SERIC), a French agent for Hewlett-Packard, the first two HP3000 systems in Ethiopia. Since then seven more have been sold by SERIC in Ethiopia and this has led to an increasingly reliable service and maintenance.

Growth of the ILCA system

Together with the bibliographic database programme (MINISIS), Statistical Package for Social Sciences (SPSS) and Biomedical Computer Programmes (BMDP) were purchased in 1980 for scientific data analysis. Shortly thereafter an animal production and linear programming packages were acquired. Administration software was first developed in-house, but has since been replaced by a commercial package.

The recent expansion of the ILCA minicomputer system is outlined in Table 1. As more staff used the computer, extra disc storage capacity was required and a 400 Mb disc was added in 1982. In 1983 the workload doubled; more central processing capacity was needed, and an extra HP3000 was ordered in late 1983. The new machine was installed in July 1984.By August the 1984 work output had already surpassed that of all of 1983.

Table 1. *Hewlett-Packard mini-computer equipment at ILCA*.

HP part number	Quantity	Description	Capacity	Year of installation
HP3000/III	1	Mini-computer	1 megabyte	1980
HP7925	2	Disc unit	240 megabytes	1980
HP7970E	1	Magtape	1600 bpi	1980
HP2893	1	Card reader	300 c.p.m.	1980
BDS 300	2	HP compatible printer	300 l.p.m.	1980
HP2621 A,B,P	20	Asynchronous terminals		
HP2647 A	1	Graphics terminal		
HP26245	1	Block mode terminal		
HP2624B	2	Block mode terminal		
HP3000/48	1	Mini-computer	2 megabytes	1984
HP7933	1	Disc	400 megabytes	1982
HP2970E	1	Magtape drive	1600 bpi	1984
HP7914E	1	Disc	132 megabytes	1984
HP2563A	1	Line printer	300 l.p.m.	1984

During 1981 and 1982 the Computer Unit analysed a backlog of data which had accumulated in the latter half of the 1970s. Field data were brought to headquarters for entry, verification and analysis on the HP3000. Initial analyses of field data had been completed by late 1982. In these analyses one major problem arose, namely the difficulty in collating, editing and correcting data when the original field documents were not available. It was decided to use micro-computers located at field stations to solve this problem.

ILCA's micro-computer network

Background

During 1981 Hewlett-Packard released the HP125 micro-computer. This ‘micro’ is based on the Z80A micro-processor chip and uses the CP/M operating system. As the HP125 can act both as an asynchronous terminal and as an intelligent terminal to the HP3000, ILCA decided to purchase two HP125s for headquarters to evaluate their suitability as a basis for a micro-computer network. Dbase II, Visicalc, Statpak, Microstat and Word 125 software were also purchased. The facility with which data could be transferred between an HP125 with its diskette and the HP3000 proved to be extremely powerful and useful.

Scientists were able to enter their data on the HP125 using database management facilities, then do initial analyses using the available statistical packages before transferring their data to the HP3000 for further comprehensive analysis. With the additional advantage of the word processing capability, ILCA decided to purchase more micro-computers for headquarters and its field programmes.

Expansion of the network

The purchase of equipment from a single manufacturer and the consequent compatibility of Hewlett-Packard micro-equipment with existing hardware was considered more important than the lower cost of possible alternative machines. ILCA spent approximately US$ 15 000 on a micro-computer system for each of two field programmes. Each system consists of an HP125, 64K bytes memory, 250K bytes disc storage (5.25" diskettes) and a daisywheel printer. A reliable power source is of utmost importance in field stations if scientists are to obtain full benefit from the micro-computers, and so uninterruptible power supplies were purchased from a UK manufacturer.

During 1982 and 1983, the network was further expanded with the installation of HP125 micro-computers at ILCA's field programmes in Kenya, Nigeria, Mali and Ethiopia. At the same time additional HP125s were acquired for ILCA's headquarters in Ethiopia. The coordination of the micro-computer network is carried out from ILCA's headquarters in Ethiopia.

Uses

After initial training and familiarisation, scientists found the micro-computers an indispensible tool both at headquarters and in field stations. In Ibadan, Nigeria, ILCA's team uses the machine for data collection and word processing, whilst in Nairobi, Kenya, the 'micro' is used predominantly for data collection and verification. This latter use is described in the case study below. At headquarters the word processing capability permits faster preparation of reports, and the ability to transfer documents via the HP3000 to the Linotype CRTronic typesetting equipment streamlines the publication process and increases throughput.

Maintenance

As ILCA was the only organisation in Ethiopia to have HP125 micro-computers, SERIC did not wish to be responsible for their maintenance. It was thus necessary that spare parts were stored at ILCA, and an agreement was made with Hewlett-Packard to replace defective boards. The purchase of three sets of the three boards that make up the HP125 increased the overall cost of the system. It was necessary to carry more than one set of spare boards because ILCA's network spans five different African countries. Whenever defects are reported, the appropriate spare boards are immediately despatched to the field programme and the defective boards are returned to headquarters to be forwarded to Hewlett-Packard. There can be a delay of up to 4 months between the failure of a board and its replacement by Hewlett-Packard.

The HP150 micro-computer

While ILCA was expanding its micro network, Hewlett-Packard were further refining their micro-computers. In August 1983 they released the HP150 micro-computer and simultaneously announced that the HP125 would no longer be manufactured. The HP150 is based on the 8088 microprocessor chip, uses the MS-DOS operating system, and belongs to the family of IBM-PC compatible micro-computers. Compatibility with the IBM-PC and the use of MS-DOS has given the HP150 a larger software base. In line with Hewlett-Packard's stated policy, ILCA had to decide whether to standardise on the HP150 or to look for an alternative CP/M compatible machine.

Once again the compatibility between the HP3000 and the HP150 was of paramount importance. Hewlett-Packard released the HP150 with software to allow similar network communication to the HP3000 as was possible with the HP125. The HP150 network software is more powerful, and Hewlett-Packard are treating HP150s as entry points to many computer networks, not necessarily based on the HP3000. Another feature of the HP150 is its capacity to read discs processed by a HP125 micro-computer. In the end ILCA's decision was simple. During 198410 HP150 micro-computers have been purchased to expand the micro-computer network both at headquarters and in the field programmes.

Many other improvements have been made in the capacity and capabilities of Hewlett-Packard micro-computers since the HP125 was released. One major improvement is the enhanced graphics capability of the HP150. Six-pen plotters can now be purchased for less than US$ 2000, so that an inexpensive HP150 system may now include graphics. A standard HP150 purchased by ILCA includes a daisywheel printer, a plotter and 250K bytes of disc storage, or alternatively 15M bytes using a Winchester disc. The micro-computers are now widely used within ILCA and have a wide variety of software. The microcomputer hardware and software currently available at ILCA are given in Tables 2 and 3.

Table 2. *Hewlett-Packard micro-computer equipment*[a] *at ILCA*.

HP part number	Quantity	Field team	Country
HP125	3	Trypanotolerance & Livestock Prod. Gr.	Kenya
HP150	1	Trypanotolerance & Livestock Prod. Gr.	Kenya
HP150	1	Kenyan Rangelands Programme	Kenya
HP125	2	Humid Zone Programme	Nigeria
HP125	1	Arid and Semi-arid Zones Programme	Mali
HP150	2	Highlands Programme	Ethiopia
HP150	1	Laboratory, HQ	Ethiopia

HP150	1	Audio-visuals Section, HQ	Ethiopia
HP150	1	Publications Section, HQ	Ethiopia
HP125	1	Ethiopian Rangelands Programme	Ethiopia
HP150	1	Personnel, HQ	Ethiopia
HP150	3	Computer Unit, HQ	Ethiopia
HP150	1	Directorate, HQ	Ethiopia

[a] Includes various configurations i.e. plotters, floppy or fixed discs, and daisywheel printers.
Note: All HP125s and HP150s located at ILCA headquarters can also act as terminals to ILCA's HP3000 mini-computers.

Table 3. *ILCA's HP150 software*.

Name	Description	Supplier
Pascal	Programming language	Microsoft
Fortran	Programming language	Microsoft
Cobol	Programming language	Microsoft
Series 100/Basic	Programming language	HP
1-2-3	Electronic spreadsheet	Lotus
Visicalc	Electronic spreadsheet	Visicorp
Series 100/Graphics	Graphics	HP
Diagraph	Graphics	Computer Support Corp.
Picture Perfect	Graphics	Computer Support Corp.
WordStar/Mail Merge/SpellStar	Word processing	Micropro Int. Corp.
MemoMaker	Word processing	HP
MiniWord	Word processing	Minisoft
DSN/Link	Communications	HP
SuperSort	Sorting	Micropro Int. Corp.
Dbase II	Database management	Ashton-Tate
Condor I	Database management	Condor Computer Corp.
R:Base 4000	Database management	MicroRim Inc.
Personal Card File	Database management	HP

Case study: The trypanotolerance network

Background

The Livestock Productivity and Trypanotolerance Group is based in Nairobi, Kenya, and focuses on the biological and economic aspects of livestock productivity, with a strong emphasis on trypanotolerant livestock. Its research is carried out with the help of a number of donor agencies in close cooperation with national institutions in 10 countries of central and West Africa where the tsetse fly and the associated trypanosome blood parasite are found.

The objective of the ILCA trypanotolerance research programme is to determine the productivity of different breeds of domestic ruminants exposed to different levels of tsetse-trypanosomiasis risk within various management systems and climatic zones. The results permit an evaluation of between-breed differences in susceptibility to trypanosomiasis throughout Africa, They also permit an assessment of the role played by acquired resistance and a between-breed comparison of the rate at which resistance develops.

Table 4 shows the management system, species and number of animals studied during 1984 in each country within the trypanotolerance network. A wide range in animal numbers must be handled. For each animal, data covering reproductive performance, weight change, milk production, health, prophylaxis and therapeutic treatments and tsetse challenge need to be recorded monthly. Considering the number of individual monthly records, it is clear that extremely large data sets build up very quickly.

Table 4. *Description of the data collected at field sites in ILCA's trypanotolerance network in 1984*[a].

Country	Management system (No.)	Species	Number of animals
Gabon	Ranch (1)	Cattle	1100
Ivory Coast	Villages (8)	Sheep	700
	Villages (8)	Sheep	500
	Villages (20)	Cattle	500
Zaire	Ranches (2)	Cattle	1000
	Villages (20)	Cattle	1000
Nigeria	Villages (10)	Sheep/Goats	750
	Ranches (2)	Cattle	450
Togo	Station (1)	Cattle	250
	Villages (10)	Cattle	380
	Villages (12)	Sheep/Goats	420
Senegal The Gambia	(starting 1985) Village (100)	Cattle	1000+
Benin (starting 1985)	Villages	Cattle	400
Tanzania	Villages (15)	Sheep/Goats	850
Kenya	Villages (3)	Cattle	1000
Ethiopia	Villages (3)	Cattle	1200

[a]Data were collected on the following subject fields: animal health and productivity; animal nutrition; tsetse; climate and ecology; socio-economics.

The network's micro system

A micro-computer unit was established to allow rapid entry, checking and filing of country data. In August 1984, the trypanotolerance network's micro-computer system consisted of 3 HP125s, 1 HP150, 2 dual floppy discs, 2 fixed discs, 3 printers and 1 plotter.

The micro-computer system is run by a staff of three. Individual animal scientists also use the micro-computers for their data storage and analysis. Training support has been limited to familiarising the supervisor with new software.

Flow of data

A well-thought-out handling system is necessary to ensure rapid entry and rational organisation of the data within the trypanotolerance network; the following discussion centres around this flow.

Field sites are supplied with simple preprinted data forms that are easily completed each month by field staff. After verification these sheets are sent to ILCA's Trypanotolerance Group in Nairobi.

Upon receipt of the data recording sheets in Nairobi, the staff who are familiar with that particular data set check it for completeness and data quality. If major omissions or inaccuracies are apparent, a memo is sent to the field site and no data entry is attempted.

If data are acceptable, they are entered at a terminal using a database management package. Use of database software speeds up the capture on magnetic media in many ways. Each field of a record is described initially so that displayed field names allow for ease of entry. For example, numeric fields will not accept alpha character data. Fields may also be set up so that they are duplicated across records, which speeds up entry by avoiding extra key strokes.

Once a data set has been entered, various flow paths are available.

In all cases several checks are made using statistical or database software. Most common are range checks using frequency or cross-tabulation routines to identify fields containing impossible values. Where errors in the original data sheet are found a memo is sent to the field site. It is important that queries be sent back to the field staff as soon as possible, while the data recording is reasonably fresh in their minds.

Using a database software master, files can be updated with additional data. Editing a master file is slow and tedious, while entering monthly data is relatively quick. Database routines that transfer additional data greatly speed up the time and accuracy of updating a master file. At this stage checks may identify animals for which monthly data have not been recorded, and this calls for a further memo to the field site.

Monthly statistics can be calculated. These are normally simple means rather than large-scale analyses, as micro-statistical software is not available for unbalanced designs. Calculation of means allows monthly trends to be plotted. Receiving monthly updates from their data provides an additional incentive for field staff to continue carrying out accurate recording. For the scientist, these monthly trends provide a tool for assessing what is occurring in the field and for preparing the layout of the major analyses that are needed.

At all times, back-up copies of data are made to avoid data losses. Copies may be made from diskette to diskette or from a fixed disc to diskette. At appropriate stages diskettes are sent to headquarters so that master files can be updated, more complex checks can be made, or the final analysis can be carried out. For the final analysis, a scientist from Nairobi usually comes to headquarters to oversee the statistical analysis that has been clearly laid out by the staff of the trypanotolerance network.

ILCA's micro-computer experience

The use of micro-computers by the Livestock Productivity and Trypanotolerance Group and the other ILCA field programmes greatly improved the control of recorded data. Capture of data onto magnetic media, checking, updating and correspondence concerning problem areas is now relatively quick. This short 'turn-around' of information maintains the interest of field staff and improves field recording. Producing data trends routinely allows scientists to stop recording data of insignificant value and start recording other data where trends indicate the need.

The establishment and running of this micro-computer network has provided ILCA with the knowledge of the many problems that must be considered in setting up a viable micro-computing facility in Africa.

Equipment

In Africa the selection of computer equipment is a particularly difficult problem as computer companies are not active in sales or maintenance. The following issues must be considered prior to the purchase of equipment.

a. Where micro-computers are to be used to capture and transfer data to a mini- or mainframe computer, compatibility must be ensured.
b. The micro-computer must have an adequate processor to carry out the required software jobs such as statistical analysis. It is advantageous if the micro's memory can be expanded and further peripherals added later.
c. Evaluation of the volume of data must be made to ensure that discs of sufficient capacity are selected.
d. Service and maintenance capabilities must exist. Obviously, it is preferable that the company or supplier has in-country facilities to ensure faster repair and routine maintenance. The alternative is to have in-house spare parts, an engineer and a method of obtaining new or repaired parts.
e. The environment in which the micro is to be used is important. A reliable power supply is imperative as drops and cuts in the electric supply can cause damage to the computer boards. Protection of equipment from heat and dust is also necessary.
f. Cost is obviously important, but in order to satisfy points a) to d), more expensive equipment may be necessary to provide a reliable working system.

Software

Evaluation and the purchase of software is extremely difficult in Africa, and contact with a software-producing organisation in Europe or North America is a necessity. Some major questions relating to software are listed below:

a. Will the product accomplish the objectives required?
b. Will the product run on the selected micro?
c. Are created files compatible with other software products?
d. Is the product easy to use?

Training

In African countries there is a great shortage of trained computer personnel. This is largely due to a lack of computers throughout the continent and the small number of universities offering computer science courses. In addition, only limited support is available from companies or suppliers. It is clear that inexperienced staff can begin to use micro-computers without much assistance, but never become competent enough to exploit fully the capacity of the computer facilities . In some cases staff are unable to install and begin using software packages. A great need for training exists.

Prospects

In view of the lack of experience and inadequate facilities within many African agricultural research organisations, ILCA believes it can offer the following assistance:

1. In conjunction with national research workers, ILCA with its mini-computer facilities helps analyse and interpret the large volumes of raw agricultural data which have been collected by national research organisations.

2. ILCA can advise national research organisations on the selection of appropriate micro-computer equipment.

3. ILCA can train African research workers in the use of computers. To date this training has been part of an overall package aimed at assisting in the analysis of accumulated national data. It is planned that courses on statistical and computer methods will be formalised at ILCA in 1985.

ILCA is developing an animal recording software package adapted to micro-computers. Using this package, national research stations can more easily monitor and evaluate their animal production data, thus facilitating optimum management decisions.

There is no doubt that micro-computer technology will enable African research workers to enter the computer age more easily and at minimal cost, ILCA seeks to assist national research groups to select, install and operate these systems.

List of abbreviations

C	Carbon
Ca	Calcium
CEC	Cation exchange capacity
CP	Crude protein
IFDC	International Fertilizer Development Center (USA)
IITA	International Institute of Tropical Agriculture (Nigeria)
IRAT	Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (France)
ITC	International Institute for Aerial Survey and Earth Sciences (Netherlands)
LIBGRIS	Land-Image-Based Geographic Information System
N	Nitrogen
NOAA	National Oceanic and Atmospheric Administration (USA)
S	Sulphur
SNF	Solids not fat
SRF	Systematic reconnaissance flights
TLU	Tropical livestock unit
UNEP	United Nations Environmental Programme (Kenya)
USAID	United States Agency for International Development (USA)