POTENTIALS OF FORAGE LEGUMES IN FARMING SYSTEMS OF SUB-SAHARAN AFRICA

PROCEEDINGS OF A WORKSHOP
HELD AT ILCA, ADDIS ABABA, ETHIOPIA
16–19 SEPTEMBER 1985

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International Livestock Centre for Africa
P.O.Box 5689, Addis Ababa, Ethiopia

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Edited by
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ABSTRACT

This volume contains 30 papers and six abstracts summarising the potentials of forage legumes in farming systems of sub-Saharan Africa and other parts of the world. Eight papers and one abstract deals with nutrient and water constraints to legume growth. Twenty two papers and five abstracts review the role of forage legumes in production systems. Recommendations for future research are also presented.

KEY WORDS

Forage legumes/N Fixation/^{15}N technique/rhizobium/phosphorus/soil water/nuclear techniques/drought stress/pasture production/inter-cropping/alley cropping/fodder banks/legume ley-farming/cropping systems/seed production/networks/farming systems/sub-Saharan Africa.

RESUME

Ce volume regroupe trente documents et six résumés sur "La contribution potentielle des légumineuses fourragères aux systèmes agricoles de l'Afrique au sud du Sahara et d'autres parties du monde". Huit de ces documents et l'un des résumés portent sur "les contraintes à la croissance des légumineuses liées à la disponibilité de nutriments et d'eau". Vingt-deux documents et cinq résumés font référence au "Rôle des légumineuses fourragères dans les systèmes de production". L'on y trouve également des recommandations pour une recherche future.

MOTS-CLES

Légumineuses fourragères/fixation de N/technique ^{15}N/rhizobium/phosphore/eau du sol/techniques nucléaires/stress hydrique/production fourragère/culture associée/culture intercalaire/banques fourragères/ley-farming de légumineuses/système culturaux/production de semences/réseaux/systèmes agricoles/Afrique au sud du Sahara.

PREFACE

The soils of sub-Saharan Africa are deficient in many nutrients, but lack of N is the most serious constraint to higher productivity from these soils. Fertilizer N is expensive and its availability sporadic; these two factors might have contributed to its limited use in the subregion.

Research over the past few decades has revealed the enormous potential of forage legumes for increasing both crop and livestock production. In cropping systems forage legumes are a cheap source of N whose presence in the soils boosts crop yields, and because of their high content of protein, they can be used to supplement animal diets.

The main objectives of the workshop were:

* To bring together scientists from sub-Saharan Africa and other parts of the world to share information on forage legumes.
* To identify production limitations specific to sub-Saharan Africa and its various production systems; and
* To recommend areas of further work where intensified research is justified in terms of scientific and practical benefits.

More than 60 scientists and development agents representing 18 countries participated in the discussions, sharing experiences and making useful suggestions. The countries represented were Austria, Australia, Congo, England, Ethiopia, Gambia, Italy, Kenya, Malawi, Nigeria, Sierra Leone, Sudan, Swaziland, Syria, Tanzania, Zaire, Zambia and Zimbabwe.

We wish to acknowledge the efforts of the authors and co-authors of papers in compiling the relevant information. We are also gratful to session chairmen John Totlill, r.K. Jones, S.R.A. Danso, A.T. Ayoub and Philip Cocks. They and other members of working groups were helpful in synthesising the discussions and developing the recommendations of the workshop.

We are grateful to Dr P. Brumby, Director General of ILCA, and Dr Frank Anderson, Team Leader, Highlands Programme, whose continued support and help made the workshop and this publication possible. Staff of ILCA's Highlands Programme, the Soils and Plant Nutrition and Forage Agronomy Sections, ILCA's Training Division, Outreach Department, the Publications and Audio-Visual and Mapping Sections and last but not the least those working in the Cafeteria and Hostels, all contributed substantially to the success of the workshop and the publication of this volume.

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S. Jutzi

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Addis Ababa, August 1986.

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ABSTRACT

This paper considers plant growth in relation to the soil. Socio-economic factors affect most farming systems and often prevent the adoption of methods that would ameliorate some of the soil-related constraints to crop and animal production. Aspects of land use in five agro-ecological zones are described.

INTRODUCTION

Climate and soil are the major factors influencing plant growth, while animal life (secondary production) is dependant on the energy captured by plants. The soil provides the physical conditions for root development and anchorage and supplies the inorganic nutrients and moisture required by the plant. Nutrient deficiencies limit plant development; deficiencies and imbalances of nutrients that have an adverse effect on plants have been identified and remedies (application of fertilizer, soil amendments, drainage and irrigation) for some conditions are available.

Because of socio-economic factors the majority of farmers in sub-Saharan Africa are unlikely to use these remedies in the foreseeable future and will continue to rely on traditional practices for soil management, including clearing and burning the natural vegetation, limited disturbance of the soil, applying organic waste and fallowing. With increasing population density some of these practices have become less practicable. However, alternating periods of cultivation and non-cultivation seems the most realistic way of maintaining soil fertility on cultivated land, although manuring with household refuse allows continuous cropping near compounds and villages.

CLIMATE

Climatic conditions in sub-Saharan Africa are frequently harsh. Rainfall varies from low and variable to very high; intense storms are common. Temperatures are generally high, although in some regions seasonal and diurnal variations are large. Insolation is intense.

LANDSCAPE

Sub-Saharan Africa is a region of enormous diversity and includes extensive plains, mountain heathlands and rain forests. However, there are areas of up to 250,000 km^2 that are remarkably uniform in climate, geology and landform.

Steepness and length of slope are important factors affecting soil erodibility and must be included in land evaluation assessments.

SOILS

A large number of soil types have been described and mapped in sub-Saharan Africa and most are highly weathered and inherently infertile. In terms of their potential for arable farming the more important associations are:- ferralsols (Oxisols[1]), luvisols (Alfisols), nitosols (paleudults and paleustults), Vertisols, fluvisols (fluvents), cambisols (tropepts) and acrisols (Ultisols).

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1. The names in brackets are the USDA Soil Taxonomy equivalents.

Appendix I gives brief descriptions of these soils.

The parent material and the degree of weathering determines the level and availability of nutrients, and the type of clay minerals; these in turn largely determine cation exchange, base saturation, the adsorption, and sometimes fixation, of P, texture, permeability, moisture retention and the stability of soil aggregates.

As a result of its chemical and physical properties, a soil may harden on drying, form a surface crust that restricts the entry of water and air and inhibits seedling emergence, develop a subsurface layer or pan that restricts root growth, be susceptible to erosion, become acid on drying, or have a subsurface horizon that hardens irreversibly on exposure.

Soil constraints to plant growth may be summarised as:

Inadequate moisture
Deficiencies/imbalances in nutrients
Low cation exchange capacity
Low base saturation
Waterlogging: impeded drainage: poor aeration
Fixation of P
Low pH (acidity)
High pH (alkalinity)
Salinity
Impermeability
Shallowness
Textural problems (crusting, hardening, stoniness)
Physical loss of soil
Induration of subsurface horizon
Temperature

PLANT GROWTH

Plant growth depends on the assimilation of carbon dioxide and the uptake from the soil of inorganic nutrients. A number of organisms can use atmospheric N. Nutrients are absorbed selectively as either anions or cations, although tropical grasses absorb both NH_4-N and NO_3-N. An excess of some elements can cause imbalances in or deficiencies of others.

Nutrients are lost from the soil by leaching, which may be accompanied by a decrease in soil pH.

Plants absorb and accumulate elements which do not appear to play any role in their nutrition and development but some of which are esential in animal nutrition, e.g. sodium and cobalt[2].

Elements that are essential for plant growth are often described according to the relative amounts required by plants as 'major' (N, P, K), 'secondary' (Ca, Mg, S) and 'trace' (Mn, Fe, B, Cu, Zn, Mo, I).

ANIMAL GROWTH

Animals obtain energy and water and other substances necessary for growth and maintenance of body function by ingesting plant materials. In many regions of sub-Saharan Africa the levels of energy, protein and P in the natural herbage are inadequate for many categories of domesticated ruminant stock; seasonally, these deficiencies may be very severe. However, it is relatively unusual for other nutrients to be deficient when the levels of energy and N in a feed are adequate. Herbage growing on certain types of soil may be deficient in essential elements, or other elements may reach toxic levels. By selective grazing the animal obtains a better diet. The leaves and fruits of woody plants can provide a valuable supplement to herbage, which may be nutritively poor. Certain elements constitute

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2. Cobalt is involved in rhizobial activity.

interrelated groups in the nutrition of the animal and the ratio as well as the level of the elements in these groups is important.

The mineral elements that are essential for animal nutrition include: Ca, Cl, Mg, P, K, Na, S, Co, Cu, I, Fe, Mn, Mo, Zn and Se. Aluminium, F, Mo and Se can be toxic above certain levels. Animals also require small amounts of a number of complex organic compounds or related substances (precursors).

SOCIO-ECONOMIC CONSTRAINTS

In sub-Saharan Africa, farms are generally small and in the majority of countries most farmers use only hand tools. Land tenure varies among ethnic groups and cultures. In some countries land is bought and sold but generally individuals or families cannot claim a permanent and exclusive right to land, although for practical purposes they have security of tenure; this security may depend on regular cultivation of the land.

The practices and farming systems developed by the cultivator are intended to ensure his survival and normally provide the maximum return for the minimum effort[3]. Good practices have sometimes been discontinued either because of shortage of labour or because they were perceived to be no longer necessary or they were no longer enforced. Some practices became less appropriate with increasing pressure on the land or because their continued use jeopardised future generations.

Fallowing is the most widely used method of maintaining fertility and has been effective and satisfactory over a very long period.

In a system found in many countries, the farmer partly clears an area by felling and burning the woody vegetation,

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3. For this reason 'minimum tillage' can be expected to be welcome by the farmer.

disturbs the soil and usually attempts to bury herbaceous vegetation. The land is then cropped until either yields decline or the work involved in weeding becomes more daunting than the task of clearing another area; the farmer then abandons the land, which is recolonised by coppicing stumps and a succession of herbaceous species.

The ratio of cultivated to non-cultivated land has been defined by Allan (1965) as:

$$L = \frac{C+F}{C}$$

where L = land use factor
C = length of cropping period
F = length of the fallow period

and by Ruthenberg (1976) as:

$$R = \frac{C}{C+F} \times 100$$

where R = cultivation factor (years of cultivation as % total cycle)
C and F as above

Ruthenberg defines	$R < 30$	as shifting cultivation;
	R 30 - 70	as semi-permanent cultivation;
	$R > 70$	as permanent cultivation.

The cultivation factor varies with the type of soil and with levels of inputs. With increasing pressure on the land the fallow period usually becomes shorter.

Houses and compounds have considerable permanency and this involves the farmer in longer journeys as the land near the compound goes out of production. More distant farms are more difficult to protect from pests and these are often allocated to migrant farmers in exchange for their labour. The migrant farmers may also work for the settled farmers in exchange for food. Share cropping is not widely practised.

Strategies for increasing agricultural production based on increased consumption and increased efficiency in the use of fertilizer frequently fail to recognise the farmers' lack of capital or credit facilities, the lack of an effective extension service and the absence of price incentives or marketing facilities for farm produce. Until agrochemical inputs are reliably available to the farmer the maintenance of soil fertility will continue to depend on fallowing.

The farming systems of most regions are usually described in terms of a small number of crops. The majority of farming families, however, grow a wide variety of crops. Interplanting two, three or more crops is widespread and appears to be soundly based[4]. This practice confuses attempts to identify and describe rotations. Ownership of livestock is widespread and there are various reasons for ownership and many different forms of management.

In tsetse-free regions of Africa the integration of crop husbandry and animal husbandry has been advocated for reasons which include the maintenance of soil fertility.

Proponents of integrated farming have frequently had a very restricted concept, e.g. 'mixed farming of northern Nigeria', and have failed to recognise that integration can occur in various forms and may involve different ethnic groups; sometimes there is little or no contact between the groups. Large-scale arable farming schemes have had a disappointing record in Africa. Yields have rarely been sufficient to justify the high cost of mechanised cultivation, while other problems have included weed infestation, pests and diseases and sometimes a succession of unfavourable seasons.

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4. More effective use of aerial space, crops are sometimes partly complementary in nutrient requirements, it minimises the effects of pest and disease attacks, combined yields usually higher than the yields of individual crops and the soil is covered for a longer period by the combination of crops.

DEFINITION OF ZONES

Different workers have adopted different criteria for defining climatic zones, including annual rainfall, the length of the growing season, months with less than 25 mm rain and months with mid-day relative humidity less than 55%. Annual rainfall and length of growing season cannot be exactly equated but they are relatively easily understood. Single peak and bimodal rainfall patterns and the seasonal occurrence of low temperatures are complicating factors.

Highlands

The highlands comprise land above 1500 m and include a number of very extensive areas as well as small scattered uplands.

Humid zone

Annual rainfall	>1200 mm
Growing season	> 270 days

The humid zone includes land that originally carried tropical evergreen and semi-deciduous forests; in West Africa it also includes the derived savannah.

Subhumid zone

Annual rainfall	=	600 - 1200 mm
Growing season	=	120 - 270 days

The subhumid zone includes areas with both single peak and bimodal rainfall patterns. The alternation of seasons is usually well defined and the dry season is frequently severe. The original vegetation in these areas was woodland with medium to tall grass ground cover.

Semi-arid zone

Annual rainfall	=	400 - 600 mm
Growing season	=	90 - 120 days (exceptionally, 150 days)

In the semi-arid zone the dry season is long and severe. The vegetation is mainly grassland with scattered trees. Both arable farming and pastoralism are important activities; in some areas human and livestock population densities are high.

Arid zone

Annual rainfall	=	< 400 mm
Growing season	=	< 90 days

Rainfall is very variable in the arid zone and vegetation is sparse. Arable farming is unreliable, and pastoralism requires mobility.

Land area, human population and livestock densities by climatic zone are shown in Table 1. The relationships between some climatic classifications and ecological zones are shown in Appendix 2.

HIGHLANDS

The main highland areas in sub-Saharan Africa are in Ethiopia, Kenya, Uganda, Rwanda, Burundi, western Zaire, Tanzania, Angola and Lesotho. There are also many other areas above the 1500 m contour and some of these afford tsetse-free grazing, e.g. Fouta Djallon and Bamenda. The highland areas vary in climate, topography, soils and land use.

Temperatures in the highlands are lower than in lowland areas at the same latitudes. Precipitation is often high

Table 1. Land area, human population and livestock densities by climatic zones.

Zone	Area ('000 km2)	Percent of sub-Saharan Africa	Rural human population ('000)	Percent of sub-Saharan Africa	Rural population density (People/km2)	TLUa ('000)	Percent of sub-Saharan Africa	Stocking density (TLU/km2)
Arid	8 327	37.3	12 000	5.3	1.7	41 697	30.4	5.0
Semi-arid	4 050	18.1	61 240	27.0	14.8	37 446	27.3	9.2
Humid	4 137	18.5	63 700	28.0	15.0	8 149	5.9	1.9
Subhumid	4 858	21.7	46 260	20.3	9.4	26 370	19.2	5.4
Highlands	990	4.4	44 000	19.4	44.2	23 646	17.2	23.9
Total or average	22 362	100.0	227 200	100.0	10.7	137 308	100.0	6.1

but, depending on the aspect of the land and the prevailing wind, can be low. Topography varies from gently rolling hills to deeply incised valleys and steep slopes. Soils are sometimes deep and fertile but shallow soils of inherently low fertility are widespread. In many mountain grassland soils only a very shallow surface horizon is fertile. Undisturbed upland areas are normally stable, although some soils exhibit 'slumping' even where undisturbed. Cultivating the so-called 'duplex' soils[5] and soils that form a surface crust on slopes results in high run off and torrents of water carrying large amounts of soil, unless soil conservation measures are taken.

Many upland areas appear once to have been well-wooded, while in other areas trees have been confined largely to valleys and stream lines. In many countries these forest resources have been exploited for charcoal and timber, which has destabilised many areas, increased the rate of stream flow (flash floods) and reduced the flow of perennial streams. In the absence of wood, dung, straw and grass are used as fuel for heating and cooking.

The farming systems of the African highlands are determined by the climate. A variety of subtropical and temperate crops, including small grains, are grown. Coffee and tea are important crops in some regions; it is more appropriate to grow these crops than arable crops on sloping land. In West Africa, earlier hill-dwelling peoples constructed elaborate terraces and maintained soil fertility by diligently composting all organic waste.

The absence of animal disease, particularly trypanosomiasis, in the uplands has attracted livestock owners. Milk collection schemes and dairying projects based on temperate breeds have been attempted with varying degrees of success. In the more extreme (latitude and altitude) conditions of Lesotho the use of many upland areas is restricted to summer grazing (transhumance) for wool sheep and angora goats. Grazing has altered the botanical

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5. Subsurface horizon of poor permeability.

composition of upland grasslands, sometimes unfavourably, e.g. when they are invaded by unpalatable shrubs, but sometimes resulting in very productive 'swards' with *Trifolium* species.

Certain farming practices result in soil being left bare for long periods. In Ethiopia, soil is gathered into heaps and burned (*guie*) to promote the release of nutrients. Although this practice is of temporary benefit, it results in serious loss of organic matter, N and S from the soil. In West Africa, farmers concentrate the fertility of the surface horizon by forming a ridge with turves from two wide strips; as a result some of the ground remains exposed even when the crop canopy is fully developed.

Getahun (1984) suggested ways of reducing the instability in the cereal-livestock ecosystem of the central and northern Ethiopian highlands, including the use of improved crop varieties and fertilizer, soil conservation methods and breed improvement. New crop varieties are unlikely to contribute to increased production unless fertilizer is applied correctly and regularly, but it seems unlikely that there will be the necessary increase in the use of inorganic fertilizer. Traditional soil conservation methods have a poor record in Africa; conservation farming, which includes keeping the ground covered and returning organic waste, is probably more appropriate. Establishing trees and wood lots for fuel, poles and fodder (agroforestry) should lessen the use of organic matter as fuel and increase its return to the soil.

Before embarking on breeding and distributing improved livestock, it is essential that the amount of animal feed available is increased. Many indigenous breeds respond spectacularly to modest improvements in their nutrition.

Many upland communities are partly dependant on non-agricultural income and employment. In many countries there is no certainty that such employment opportunities will continue. The need to improve agricultural production, and to develop markets and rural agro-industries in upland regions is urgent.

HUMID ZONE

The humid zone is found at low latitudes, north and south of the equator. Soils include ferralsols, acrisols and luvisols, the last of which are commonly encountered at the forest-savannah boundary. The natural vegetation is tall, closed forest which may be evergreen or semi-deciduous and is often floristically rich. The herbaceous vegetation often contains large amounts of the major nutrients. The top soil contains relatively large amounts of organic matter, which markedly improves its characteristics. Removal of the trees interrupts the nutrient cycle.

Tree crops, including oil palm, cocoa, rubber and plantains, are ecologically similar to the forest vegetation and are grown both in plantations and associated with food crops on small scattered farms. There are few livestock in the humid zone.

Land is cultivated by hand. In the absence of herbaceous vegetation, clearing the land is relatively easy. The soil is exposed for only brief periods and the cultivation period is normally short. In some parts of the humid tropics, crops are grown on mounds which provide better aeration and more nutrients but their construction involves greater disturbance of the soil.

Increasing population density has shortened fallow periods. Mechanical cultivation may result in soil compaction, erosion and the exposure of subsurface soil. Using inorganic fertilizer to extend the cultivation period may lead to the depletion of base cations and lower the pH of the soil.

The value of minimum tillage systems has been demonstrated, although not all soils are suitable for zero-tillage systems, e.g. clays without natural tilth-forming properties. Cover crops and alley farming companion crops provide both cover and organic matter for the soil. Small dressings of lime (1 t/ha) have sometimes shown benefit but excess lime may induce trace-element deficiencies on luvisols and acrisols.

SUBHUMID ZONE

Within the climatic definition, this is a very varied zone in terms of climate, soils and land use. Luvisols and cambisols occur widely. Parent material is often strongly weathered, the levels of mineral nutrients are low and the clay fraction is of low activity. Cambisols have fewer constraints to plant production than the older, more weathered soils. With their high base status, there is adequate Ca and no constraint due to low pH. The fertility of many soils is low and their structural stability is poor; they crust and harden when dry. Leaching of NO_3 is accompanied by the loss of cations and P is adsorbed.

The natural vegetation is a medium-height or low woodland with understory shrubs and a ground cover of medium to tall, mainly perennial, grasses; *Hyparrhenia* spp. are common.

A wide range of crops is grown, including yams, sweet potatoes, maize, sorghum, soya bean, grain legumes, cotton, and sesame. Intercropping is usual. The incidence of *Glossina* spp. (tsetse) restricts livestock populations. Most settled families have smallstock; ownership of cattle and the use of animal-drawn implements vary between and sometimes within countries. This zone often provides grazing for large populations of transhumant cattle whose movements reflect seasonal variations in the severity of the tsetse challenge.

Cultivation involves clearing or, more frequently, partly clearing woody vegetation by ring barking and/or felling trees and burning. It is not possible to plough (ridge) or hoe the soil until sufficient rain has fallen to soften it. Considerable disturbance of the soil is needed to bury the herbaceous vegetation or, after burning, root material. In the first year of cropping, the decomposition of organic matter 'locks-up' N, and farmers will choose crops that either can be planted late or are less adversely affected by low levels of N. In subsequent years, levels of P in the soil may be low.

Herbicides will be essential if minimum tillage methods are adopted in the subhumid zone.

Newly cultivated soils will often appear to have a good tilth but this is quickly lost and severe crusting occurs Crusting hinders seedling emergence and reduces the entry of water and air. Unless such measures as tie-ridging are used severe run-off of water can occur, which may result in soil erosion. Well grown crops protect the soil and their roots improve the soil texture and increase infiltration of water in the same and in the following year. Organic matter reduces the strength of crusts; farmers recognise the value of manure in improving crop yields.

In many subhumid areas the control of weeds, particularly grass weeds, is the most difficult of the farmers' tasks, and the increase in the weed population is often the pricipal reason for abandoning a farm. Weeds on fallow land are often grazed eagerly by stock. In addition to upland and sometimes flood-plain grazing, other sources of feed for livestock are cereal and grain-legume crop residues and the leaves and fruit of a variety of woody plants (browse). The nutritive value of upland perennial grassland is adequate for a short period early in the wet season only and subsequently its nutritive value declines rapidly. For much of the year the straw-like material is of little value. The level of protein in the herbage reflects the level of available N in the soil. At the beginning of the wet season there is a flush of N, as a result of rapid mineralisation of organic matter exposed during the dry season. Subsequently, mineralisation is less rapid and soil micro-organisms compete with the grass for the NH_4-N.

Grazing the grass results in the regrowth of young material of higher nutritive value and also extends the vegetative phase by delaying the development of flowering stems.

The low nutritive value of the natural herbage for much of the year is the most serious constraint to animal production in this zone. Improvement of fodder quality is one of the benefits of conventional integrated crop and animal husbandry. The availability of manure for crops is often considered to be the principal advantage of integrated systems.

In some areas, farmers allow pastoralists to graze their cattle on crop residues, thereby benefiting from the manure. Money, food and milk may also be exchanged. Where root crops are grown in West Africa no edible crop residues are produced and there is little contact between the cultivator and the pastoralist. As a result, crop-livestock integration would appear to be non-existent. However, in parts of the Nigerian tsetse belt increased cultivation has eliminated the tsetse fly and pastoralists can remain year-round. The benefit to the cultivator is that the fertility of fallow land increases more rapidly under grazing than that of ungrazed areas, which are swept by fires in the dry season in most years. In this situation the number of cultivators and the intensity of land use are critical, and a further increase in the number of cultivators is likely to jeopardise the continuation of this unplanned system of soil fertility maintenance.

SEMI-ARID ZONE

The low rainfall and the long dry season make the semi-arid zone a relatively healthy environment for man and his livestock. Arenosols and cambisols are widespread and include coarse sandy soils, fine sands, and loamy sandy soils. Water retention is poor and nutrient contents, including N, P and S levels, are low. The permeability of the undisturbed soil is good. Algal skins contribute to the formation of surface crusts. The natural vegetation is an open, low-tree grassland but has been severely modified in many regions.

Population density in the semi-arid zone is very variable but is high in West Africa and in some areas in East Africa. Crops include sorghum, millet, grain legumes and groundnuts. In areas close to markets, tomatoes, onions and vegetables are grown on land that can be watered in the dry season. Livestock are owned by settled farmers and by semi-settled pastoralists. The livestock population is often large and is frequently swelled by the influx of transhumant cattle herds. Animals are widely used for cultivation.

Although nutrient levels are low, inadequate soil moisture is probably the most serious constraint to crop production. Periods of more than three or four days without rain result in the death of seedlings and also cause stress in older crops, resulting in reduced yields.

Fertility is maintained by applying compound waste and animal manure to the land and by fallowing. The benefit of fallowing seems mainly to be in the accumulation of P and other nutrients, including S. Trees such as *Acacia albida* contribute to the fertility of arable land. Cultivated land remains bare for many months between short cropping periods.

The production of herbage is correlated with rainfall and is spatially and seasonally variable in amount and quality. The level of protein in the dry-season herbage is better than that in the subhumid zone and is supplemented by the leaves and fruit of a variety of shrubs and trees which are browsed; crop residues are also a valuable source of fodder. Overgrazing and overbrowsing is resulting in the deterioration of the forage resources in many parts of semi-arid Africa. Termites and harvester ants discourage attempts to grow forage/fallow crops. In many areas trees have been exploited for fuel or ruthlessly lopped for fodder; the need for fuel is likely to result in little organic matter being returned to the soil.

ARID ZONE

Rainfall is low and extremely variable in the arid zone. The sandy soils (arenosols) are weakly differentiated and are often of aeolian origin. Water and air move freely through the soils, which are low in all nutrients. The vegetation consists of scattered shrubs in a sparse cover of mainly annual grasses. Arable farming is unreliable and restricted to opportunistic cultivation of short-season millets, except in topographically favourable sites. Mobile herds of sheep, goats, cattle and camels utilise the herbage and shrubs. Pastoralists frequently use these arid zones seasonally and have a well-defined system of transhumance. The quality of the herbage is inversely correlated with rainfall. The herbage remains palatable in the dry season but much is destroyed by wind and by termites. In the arid zone it may be more appropriate to estimate carrying capacity on the protein content of the herbage rather than on the quantity of herbage. Overgrazing reduces the ground cover of the herbage and adversely affects the botanical composition. Investments other than the development of water and stock-handling facilities are unlikely to be cost-effective.

The number of people that the pastoral systems in the arid zone can support is low and increased numbers of pastoral people have already jeopardised the continuation of this way of life in a number of countries. It will not be easy to identify acceptable strategies to ensure their survival but in the absence of such strategies our current ability to monitor the forage resources of arid and semi-arid Africa will only provide a record of increasing desertification and chart the demise of the pastoralist.

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APPENDIX I.

Acrisols	Extremely leached soils with low nutrient levels. Argillic B horizon reduces permeability and root development and increases susceptibility to erosion.
Arenosols	Coarse sandy soils with low water retention and low in nutrients. Susceptible to wind and water erosion.
Cambisols	Mostly young soils with fewer constraints than older weathered soils. Fine sandy soils and loamy sandy soils are common.
Ferralsols	Old weathered soils poor in plant nutrients; low CEC and deficient in bases. Fixation of phosphate occurs in clayey fine-textured soils. Aluminium and micro-element toxicites may occur. Coarse textured soils are susceptible to erosion.
Fluvisols	Young soils whose characteristics depend on the parent material, which is mainly alluvium. Inundation and waterlogging are common. Thionic fluvisols (acid sulphate soils) require skilled management as drainage and aeration result in extreme acidity.
Luvisols	Very varied soils occuring in both subhumid and semi-arid zone. More strongly weathered in the subhumid zone than in the semi-arid zone and the degree of weathering affects the level of plant nutrients. Low aggregate stability, surface sealing and erosion susceptibility are common. Poor retention of water; pH falls with continuous use.

Nitosols	Permeable soils with good moisture holding capacity to deep argillic B horizon. Weatherable minerals present and less acute nutrient deficiencies than the ferralsols. Low CEC phosphorus fixation is common.
Vertisols	Dark expanding clay soils; intractable as a result of their texture. Base saturation is high. High water retention but moisture stress is common.

APPENDIX 2. Classification of climatic and vegetation zones in Africa.

Mean annual rainfall mm	Thornthwaite (1948)	Keay (1959)	Yangambi Conference (1956)	White 1983 UNESCO	Jankhe 1982	Houérou & Popov FAO	ILCA
0		Desert		Desert		Desert	
100			Steppe		Arid		Arid
200						Very arid - - - and arid	
300	Arid	Sahel					
400				Sahel		Semi-arid	Semi-arid
500			Tree or shrub steppe				
600						Dry subhumid	
700	Semi-arid	Sudan			Semi-arid		
800				Northern Sudan (northern Miombo)			Subhumid
900						Subhumid	
1000			Tree savanna				
1100	Dry subhumid	Northern Guinea		Southern Sudan			
1200					Subhumid		
1300		Southern Guinea	Savanna woodland			Humid	
1400	Moist subhumid			Guinea			
1500							
1600		Derived savanna	Dense forest				Humid
1700					Humid	Hyper humid	
1800	Humid						
1900		Rain forest	Dense rain forest	Forest			
2000							

ASSESSMENT OF DINITROGEN FIXATION POTENTIALS OF FORAGE LEGUMES WITH ^{15}N TECHNIQUE

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ABSTRACT

A great advantage with the use of ^{15}N isotope dilution technique to estimate N_2 fixed is its ability to give an integrated estimate of N fixation over a growing season or longer. It is the only method that can distinguish between soil, fertilizer and fixed N in field-grown crops. The technique has thus been extensively employed to quantify N-fixation in forage legumes, and there is an ever increasing interest in its use, as shown by recently published literature. Estimates made using the isotope dilution technique have established that most forage legumes derive a large proportion of their N from fixing atmospheric N_2 and, in general, this is in excess of 70 - 80 % of their total N requirements.

The determination of the level of N-fixation by the ^{15}N isotope dilution technique requires an assessment of the $^{15}N/^{14}N$ ratio in soil. This assessment is made by selecting an appropriate reference crop to assess the soil's $^{15}N/^{14}N$ ratio. Errors associated with using poor reference crops may be high at low values of fixation but become negligible at high values of fixation. With such a high proportion of the N in forage legumes generally coming from fixation therefore, the effect of a poor choice of a reference crop on N_2 fixation estimate is low. Furthermore, the evaluation of the

qualitative effect of treatments on N fixation requires no reference crop, if the treatments being compared received the same amount and enrichment of ^{15}N-labelled fertilizer. They can be ranked simply by comparing the ^{15}N enrichments within the legumes; the lower the $^{15}N/^{14}N$ ratio, the better the fixer it is. Only a quantitative determination of the magnitude of the effect requires use of a suitable reference crop.

The criteria that need to be observed in selecting suitable reference crops include: lack of N_2-fixing ability, N-uptake patterns of the legume and the reference crop should match closely, similar periods for planting and harvesting, and proper sampling procedures.

INTRODUCTION

In addition to forage legumes serving as rich sources of proteins for animals, there is currently a great interest in the use of legume-based forages in cropping systems for maintaining soil fertility and controlling erosion. Although many legumes have been shown to derive large amounts or proportions of their N from fixation (Walker et al, 1956; Henzell et al, 1968; Boddey et al, 1984; Heichel et al, 1981; Vallis et al, 1967; 1977, Heichel et al, 1985; West and Weding, 1985), it is also known that several factors can influence how much N_2 is fixed in forage legumes (Vallis et al, 1967; Lynd et al, 1984; Carter and Sheaffer, 1983; Allos and Bartholomew, 1955; Chu and Robertson, 1974; Yamanaka and Holl, 1984). To exploit this natural and inexpensive source of N for optimum forage yields more effectively, therefore, reliable methods are needed to quantify biologically fixed N in forage legumes.

Various methods have been used to provide estimates of N_2 fixed in forages, each of which has its own merits and disadvantages. Nodule number, weight and plant dry weight are among the earliest, most inexpensive and simplest methods (Bowren et al, 1969; Bell and Nutman, 1971; Heichel and Vance

1979; Heichel et al, 1984). Nodule parameters and plant yield, however, provide only indirect evidence of the extent of N_2 fixation. They do not give a measure of how much N_2 is fixed, neither do they always give an accurate indication of how much N_2 is fixed (Danso, 1985).

The total N difference between a fixing and a non-fixing crop has been extensively used to estimate N_2 fixed in various legumes (Williams et al, 1977; Boddey et al, 1983; Broadbent et al, 1982; Phillips et al, 1983; Legg and Sloger, 1975; Bell and Nutman, 1971; LaRue and Patterson, 1981). The non-fixing crop is used to assess the amount or portion of the fixing crop's total N that came from soil. The assumption therefore is that the two crops, which may even belong to vastly different species, take up similar amounts of soil N. As pointed out by Rennie and Rennie (1983) and Danso (1985), the validity of this assumption is doubtful in most cases. The method also lacks precision. Moreover, where soil or fertilizer N levels are relatively high, N_2 fixation may be low enough to be obscurred by sampling, analytical and other experimental errors (Vose et al, 1982). However some N-difference estimates in good agreement with ^{15}N-determined values for fixation have been reported (Ham, 1978; Broadbent et al, 1982; Phillips et al, 1983; Legg and Sloger, 1975).

The acetylene reduction technique of Hardy et al (1968) has been widely employed to estimate the nitrogen-fixing capacity of forage legumes (Goh et al, 1978; Heichel and Vance, 1979; Vance and Heichel 1981; Heichel et al 1981; Legg and Sloger, 1975; lynd et al, 1984; Yamanaka and Holl, 1984; Heichel et al, 1984). Although simple, inexpensive and sensitive, this technique suffers from serious drawbacks, particularly since it is only a short-duration enzyme activity assay which does not take into account the existence of diurnal and seasonal variations in dinitrogen fixation (Ayanaba and Lawson, 1977; Vaughn and Jones, 1976) and thus makes extrapolation of such instantaneous assays to total nitrogen fixed over a growing season questionable. In addition, conventionally, a ratio of 3 is used to convert acetylene reduced to amount of N_2 fixed, but this ratio has been found to vary widely among plants and in different environments (Bergersen, 1970; Goh et al, 1978; Hudd et al, 1980; Rennie et al, 1978; Knowles, 1981). Above all, the method is not well suited to field studies.

Since N_2 is the substrate for N_2 fixation, incorporation of $^{15}N_2$ into plant tissues invariably provides the most direct and valid estimate of how much N_2 is fixed. This technique, which was first used by Burris and Miller (1941), however, cannot be employed in field experiments, since it is not practicable to label all the N_2 in the atmosphere in a normal field experiment (Fried et al, 1983). Its use has therefore been restricted to studies in closed chambers (Witty and Day, 1978; De-Polli et al, 1977).

However, by using the differences that exist in ^{15}N enrichment of soil and the atmosphere (natural ^{15}N-abundance technique), or by artificially inducing such a difference through the addition of ^{15}N-enriched or depleted fertilizers to soil (in several reports called ^{15}N-isotope-dilution method), it has been possible in the field to estimate directly the proportion or amount of N in a plant that is derived from symbiotic N_2 fixation (McAuliffe et al, 1958; Vallis et al, 1967; Fried and Broeshart, 1975; Fried and Middelboe, 1977; Legg and Sloger, 1975; Kohl and Shearer, 1981; Bergersen and Turner, 1983; Broadbent et al, 1982; Heichel et al, 1985). According to Chalk (1985), more than 50 research papers on N_2 fixation involving the addition of ^{15}N enriched and depleted materials to soil have been published since 1975. Much of this interest in the technique is attributable to its applicability in the field and its ability to give an integrated estimate of N_2 fixed over one or several growing seasons. The lowered cost of ^{15}N-labelled fertilizers and the availability of cheaper instruments for $^{15}N/^{14}N$-ratio analysis have also undoubtedly made a significant contribution. This paper will therefore be devoted largely to the use of ^{15}N-enriched soils in N_2-fixation studies.

PRINCIPLES OF THE METHOD

The ^{15}N-isotope-dilution principle stipulates that changes in ^{15}N enrichment result when two sources that differ in N isotopic composition are uniformly mixed. The extent of change that results will depend on the magnitude of the differences in the initial enrichments of the individual sources, as well as the relative amounts of each. The isotope dilution equation for two sources may be written simply as:

$$a = \frac{x\,(a_1) + y\,(a_2)}{(x + y)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where: x = quantity of N fertilizer of higher enrichment with ^{15}N abundance of a_1.

y = quantity of N fertilizer of lower enrichment with ^{15}N abundance of a_2.

and a = final ^{15}N abundance of the mixtures of x + y.

If y is of natural abundance, then:

$$a = \frac{x\,(a_1)}{(x + y)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

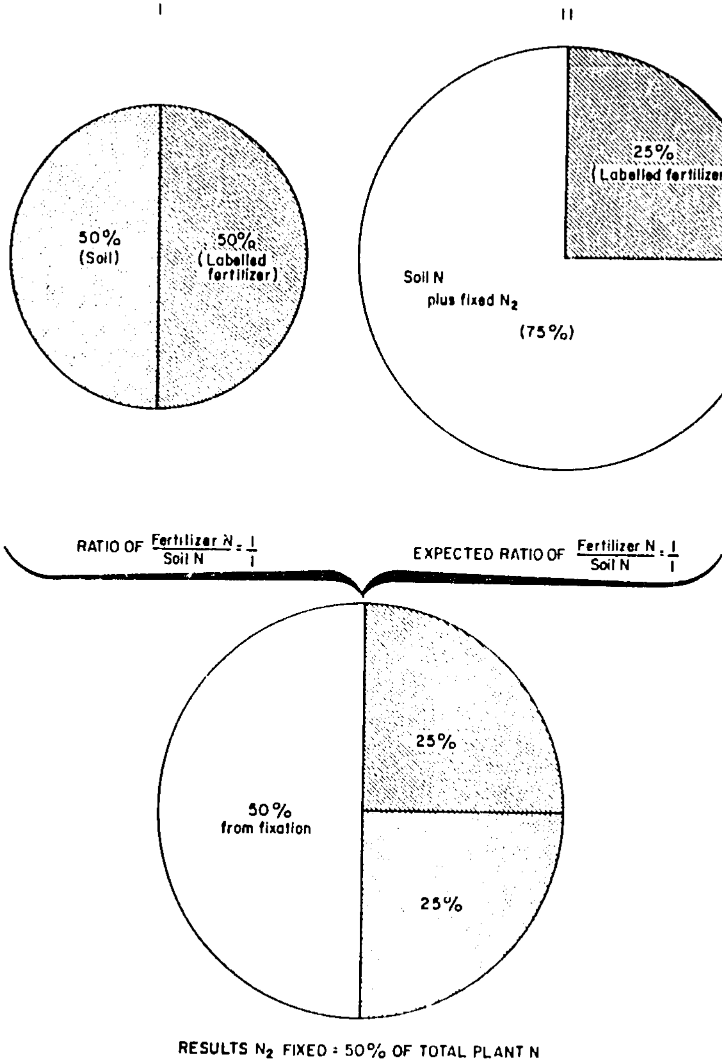
Thus, by adding ^{15}N-enriched fertilizers to soil, plants take up N from soil with higher ^{15}N composition than the approximately 0.3663 atom % ^{15}N present in the atmosphere. The extent to which this higher $^{15}N/^{14}N$ ratio is lowered in a fixing plant by the lower $^{15}N/^{14}N$ ratio from the atmosphere is then a reflection of the magnitude of fixation.

It is therefore important to establish as accurately as possible the resultant $^{15}N/^{14}N$ ratio in the soil into which material with higher $^{15}N/^{14}N$ ratio has been incorporated. This, however, cannot be established easily by chemical extraction since the various soil sinks which provide N to the plant may have different $^{15}N/^{14}N$ ratios. Also, depending on how and when the ^{15}N is applied, the ratio may not remain constant but may decline during the growing season, especially shortly after incorporation (Fried et al, 1983; Witty, 1983; Vallis et al, 1967). A reference crop that does not fix N_2 has thus routinely been used to establish the integrated ratio of 15N/14N in soil over the whole growing season (McAuliffe et al, 1958; Vallis et al, 1967; Fried and Middelboe, 1977; Fried et al, 1983). This is represented in Figure 1. The original equation for estimating the proportion of N in a legume derived from N_2 fixation as presented by McAuliffe et al (1958) involved first estimating the proportion of N in the legume derived from soil (X_1) from the ratio E_L/E_{GL}, where E_L and E_{GL} are the enrichments of 15N in the legume and grass, respectively. The proportion of N from fixation is then given by $1 - X_1$. This is essentially similar to the equation given by Fried and Middelboe (1977) for calculation of the percentage of N_2 fixed as:

$$\%\ \text{Ndfa} = \left(1 - \frac{\text{atom \% }^{15}\text{N excess in legume}}{\text{atom \% }^{15}\text{N excess in reference}}\right) 100 \quad \ldots.(3)$$

The use of natural ^{15}N abundance for N_2 fixation estimation requires that the 15N/14N ratio in the soil differs appreciably from that in the atmosphere, and is based on the same principles as above. It has been shown that many soils have higher ^{15}N enrichments than the N_2 in the surrounding atmosphere (Shearer et al, 1974; 1978; Cheng et al, 1964; Rennie et al, 1978; Virginia, 1980). Thus, soils seem to be naturally enriched in ^{15}N, and the dilution of this by N_2 derived from the atmosphere has been used to estimate N_2 fixed in grain legumes (Amarger et al, 1979; Domenach et al, 1979; Ruschel et al, 1979; Kohl et al, 1980; Rennie, 1982; Rennie and Kemp, 1983) as well as forage legumes (Edmeades and Goh, 1979; Bergersen and Turner, 1983; Turner and Bergersen, 1983). A reference crop is again needed to establish the $^{15}N/^{14}N$ ratio in the soil. Given the

Figure 1. *Schematic diagram of the principle behind the use of the isotope dilution technique to estimate nitrogen fixation in crops.*



usually small differences in ^{15}N enrichments between soil and atmosphere, such differences are expressed in $^{0}/00$ units, i.e.,

$$\delta^{15}N = \frac{R\ sample - R\ reference}{R\ reference} \quad ....(4)$$

and

$$\delta^{15}N\ ^{0}/00 = \left(\frac{R\ sample}{R\ reference} - 1\right) 1000 \quad ....(5)$$

where $R = {}^{15}N/({}^{14}N + {}^{15}N)$ and the reference is taken as the ^{15}N enrichment in air, and is by definition equal to zero (Amarger et al, 1979).

Delwiche and Steyn (1970) have shown that isotopic fractionation of ^{15}N and ^{14}N occurs during biological dinitrogen fixation. In view of the hioh enrichments involved where ^{15}N-labelled compounds have been added to soil, this isotopic discrimination between ^{15}N and ^{14}N normally does not affect the accuracy of the measurement or interpretation of results (Edmeades and Goh, 1979, Hauck and Bremner, 1976), while unless corrected for, significant errors could be introduced in the estimates of N_2 fixed made by the natural abundance technique (Amarger et al, 1979; Mariotti et al, 1980; Kohl and Shearer, 1980). Isotopic fractionation can be assessed by growing legumes on sterilised sand watered with a nitrogen-free medium and estimating N isotopic composition in these plants dependent solely on N_2 fixation. The new reference, $^{15}N_F$ is then given by:

$$\delta^{15}N_F = \delta^{15}N_{air} + \varepsilon \quad ....(6)$$

in which $\delta^{15}N$ air is equal to zero and ε is the isotopic fractionation that occurred within the plant upon utilising atmospheric nitrogen. Nevertheless, because $^{15}N/^{14}N$ differences are small and discrimination values obtained experimentally vary from investigator to investigator, the method is still at a developmental stage.

In the ^{15}N methods described above, the amount and enrichment of ^{15}N material added to the legume and reference plots have to be the same. The amounts of N added often have to be small since high soil inorganic N levels normally inhibit N_2 fixation (Butler and Ladd, 1985a; Allos and Bartholomew, 1955; Haystead and Marriott, 1979; Heichel et al, 1985). Under N-deficient conditions, however, the small amounts of N added so as to avoid interference in N_2 fixation by the legume may be inadequate to support normal growth of the reference crop. By using the A-value approach of Fried and Broeshart (1975), it is possible to add different amounts and ^{15}N enrichments to the legume and non-legume and still make valid estimates of N_2 fixed. The basic concept behind this methodology is that plants will take up N from soil and any other sources in direct proportion to how much of each is available to the plants (Fried and Dean, 1952). This implies that the amount of N available in a given soil is the same for different crops exploiting N from a similar zone, and is also unchanged even under different fertilizer N levels (Aleksic et al, 1968). The A-value is estimated by the following equation of Fried and Dean (1952):

$$A = B\,(1 - y)/y \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

where A is the amount of a given nutrient available in, for example, soil (A_s), B is amount of fertilizer N added, and y is the proportion of N in the plant derived from fertilizer.

Thus for a crop like a legume which derives N from soil, fertilizer and fixation,

$$\frac{\%Ndff}{A_f} = \frac{\%Ndfs}{A_s} = \frac{\%Ndfa}{A_a} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

where % Ndff, Ndfs and Ndfa refer to the proportions of N derived from fertilizer, soil and fixation, respectively.

The non-fixing crop estimates A_s, while the legume estimates $A_a + A_s$, and subtracting the latter from the former gives A_a. % Ndfa is then equal to

$$\frac{\%Ndff \times A_a}{A_f} \qquad \text{.................................(9)}$$

where % Ndfa is the proportion of N derived from fixation.

Although the A-value approach has been a subject of much controversy (Broadbent, 1970; Boddey et al, 1983; Vose et al, 1982; Rennie and Rennie, 1983), several studies (Phillips and Bennett, 1978; Williams et al, 1977; Heichel et al, 1981; Wagner and Zapata, 1982) have reported good estimates made using this method. The A-value approach cannot, however, be used in mixed pasture stands unless a suitable external standard is used, as it involves the application of two separate rates.

REFERENCE CROPS

Reports in the literature reveal that perennial ryegrass is about the most commonly used reference crop for estimating N_2 fixation in forage legumes. Others that have been used include spear grass and Rhodes grass (Vallis et al, 1967), Pangola grass (Vallis et al, 1977), salt chess grass (Williams et al, 1977), barley (Witty, 1983), *Dactylis glomerata* (West and Wedin, 1985), tall fescue and red canary grass (Heichel et al, 1985).

Reference crops are needed solely for the assessment of the soil's $^{15}N/^{14}N$ ratio over the growing period. They are therefore not essential when only qualitative differences between N_2 fixed in different treatments (which have received similar amounts ^{15}N enrichments of N fertilizer) are required. However, when accurate amounts or proportions of N_2 fixed are needed, a reference crop has to be used and this constitutes the greatest potential source of error in the ^{15}N technique for determining N_2 fixation in field experiments.

For example, with $(NH_4)_2SO_4$ as the source of ^{15}N, nodulated soya beans in Senegal were estimated to have fixed 71 kg N/ha in the field relative to a non-nodulated soya bean control, while fixation by the same plants with sudan grass as a control was estimated as 40 kg N/ha (Ganry, personnal communication). The selection of an appropriate non-fixing crop is therefore crucial under such circumstances, while, on the other hand, the error made by using an improper reference crop may be negligible where the $^{15}N/^{14}N$ ratio in soil remains constant during the period of growth, or where the proportion of the plant's N that is fixed is very high, as is typical of many forage legumes. In the case of established pastures, the non-fixing companion crop in the mixture, if any, or the weeds growing together with the forage legumes is usually used as reference crop. It is, however, desirable to establish their suitability since these companion crops in some cases may not be appropriate as controls.

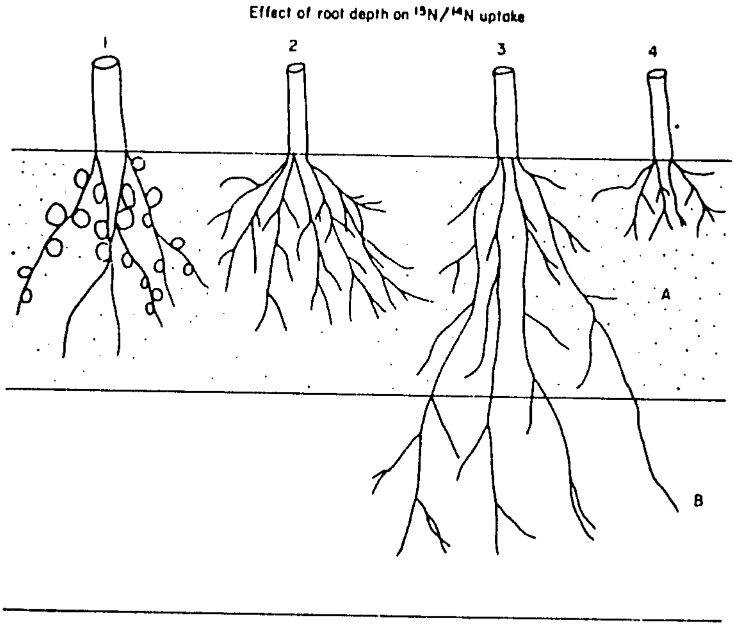
Fried et al (1983) list the following criteria which have to be considered in assessing the suitability of a crop as a reference:

Absence of N_2 fixing activity: Although at present most forage legumes do not have suitable non-nodulating isolines, the absence of substantial acetylene reduction activity in suitable crops is enough to ensure that a potential reference crop does not fix N_2 (Fried et al, 1983; Phillips and Bennett, 1978).

Relative N uptake patterns: The N uptake profiles of the reference and fixing crop should match as closely as possible, since the $^{15}N/^{14}N$ ratio of ^{15}N-enriched soil does not normally remain constant but usually declines with time (Vallis et al, 1967; Witty, 1983; Fried et al, 1983). The basic assumption in using a reference crop therefore is that the two types of crop will take up soil $^{15}N/^{14}N$ in the same proportion throughout growth and, in the case of perennial forages, also within different harvests, so as to reflect the changing soil $^{15}N/^{14}N$ ratio. According to Witty (1983), even relatively small differences in N-uptake profiles of fixing and non-fixing crops could lead to as much as 50% error when the rate of change in soil enrichment is high. Unequivocal proof that the fixing and non-fixing crops are deriving N of the same isotopic composition throughout a growth cycle is, however, often difficult to obtain directly, and the few N_2-fixation studies that have attempted to establish this have done so through indirect approaches (Witty, 1983; Fried et al, 1983; Wagner and Zapata, 1972). A time-course study of growth and nitrogen uptake is quite useful in ascertaining that the potential reference crops do not deviate appreciably in N uptake from the forage legumes of interest (Heichel et al, 1985). A suitable solution to this problem is to label the soil in such a way that the $^{15}N/^{14}N$ ratio does not change appreciably with time. In addition to the decline in $^{15}N/^{14}N$ ratio with time, there is normally spatial variability of this ratio with soil depth in field soils due to non-homogeneous mixing (Ladd et al, 1981b). Thus, although it has been pointed out by Fried et al (1983) that the essential prerequisite is the absorption of N from a similar zone of incorporation (designated A in Figure 2) as shown by crops 1, 2 and 4 in Figure 2, rather than from the same depth, if the vertical gradient of ^{15}N is substantial, problems could arise by using crop 4, which could otherwise have been a good reference. Ideally, the soil should be uniformly labelled to the depth that is explored by the plant roots, as suggested by Boddey and Victoria (1985), but this is difficult to achieve in a field experiment. Luckily, many forage legumes tend to be shallow rooted, and it should not be too difficult to get equally shallow rooted non-fixing plants to test for suitability as reference crops. In addition, a large proportion of the available nitrogen is in the surface layer in most soils.

Relative effect of environment on reference and fixing crops: In using reference crops to estimating N_2 fixed in forage legumes, it is essential to ensure that both fixing and non-fixing crops are adapted to the climate of the area. Some

Figure 2. *Diagramatic representation of the principles underlying the selection of an appropriate reference crop to assess soil $^{15}N/^{14}N$ ratio taken up by a fixing crop.*



forage legumes adapted to cool environments may do poorly in warm environments and vice versa. Reference crops for cool-season forage legumes should also be capable of growing under cool conditions, otherwise the periods of growth/ establishment could be different and, as pointed out by Fried et al (1983) and Witty (1983), while the adapted crop may grow early and utilise much of the N of high $^{15}N/^{14}N$ ratio during the initial period of N addition, the unadapted and late-developing crop will only take up substantial amounts of N when the $^{15}N/^{14}N$ ratio is quite low. An important criterion for the validity of the ^{15}N technique, that both fixing and non-fixing crop will take up N of the same isotopic ratio throughout the period of growth, will then not be met if the soil's N isotopic composition changes with time. For example, in an experiment on N_2 fixation in *Vicia faba* during the cool season in Egypt, sudan grass, wheat and barley were assessed for suitability as reference crops. Wheat and barley, which are cool-season crops like *Vicia faba*, were found to be suitable and gave a similar estimate of N_2 fixed, while sudan grass, a warm-season crop, was not suitable and gave a substantially lower figure for the amount of N_2 fixed (Hamissa, personal communication). This effect was, however, negligible on the N_2-fixation estimate made on faba bean, which derived more than 80% of its N from fixation, but was large for chickpea, which fixed less than 30% of its N. A late-developing reference crop could therefore underestimate nitrogen fixation, and in low-fixing crops, negative values of estimated fixation may be obtained (Witty and Ritz, 1984). In perennial crops, such as many forages, the reference and fixing crops do not have to be adapted only to climatic factors over one season, but possibly over several seasons and even years.

Time of growth of reference and fixing crops: In all N_2-fixation studies, it is essential that both the reference and the fixing crop are planted and harvested together. Since many N_2-fixation studies in forage legumes have involved mixed crops, often both crops have been harvested together even though the different crops have been separated from each other during or after harvest. A few cases involving different planting dates due to, e.g. replanting of one crop (Vallis et al, 1967) have been reported, and this should be avoided as much as possible, since under such circumstances both the fixing and the non-fixing crops may not be taking up N of the same isotopic composition throughout growth (Fried et al, 1983).

Cropping systems: Forages may be grown alone (Simpson, 1965; Williams et al, 1977; Butler and Ladd, 1985a; Phillips et al, 1983) or, as is the common case, in mixtures with grasses (Vallis et al, 1967; Henzell et al, 1968; Broadbent et al, 1982; Butler and Ladd, 1985b; Haystead and Lowe, 1977; Heichel et al, 1985). With sole forage legume cultivation, identical plots of a sole crop of the reference species have often been established. In the case of stands of legumes and non-legumes, an additional or optional choice is in using the non-fixing crop within the mixture. However, competition by a non-legume growing in association with forage legumes has been found to affect the growth and nitrogen uptake of the latter (Vallis et al, 1967; Henzell et al, 1968; Butler and Ladd, 1985b). Thus, in order for the use of a sole non-fixing crop to estimate N_2 fixed in mixtures to be valid, it is essential to establish that the sole reference crop and forage legume in the mixture (and not alone) have similar N uptake and/or growth patterns. A second assumption is that the reference crop growing alone and the forage legume in the mixture are sampling soil of similar $^{15}N/^{14}N$ ratios. However, since forage legumes often add more litter to the soil than do grasses (Birch and Dougall, 1967; Vallis et al, 1977), decomposition of the forage legume residues with lower $^{15}N/^{14}N$ ratios may lead to decreased $^{15}N/^{14}N$ ratios in soils under the mixed sward than under pure grass stands (Heichel et al, 1984). Should this happen, it is not correct to use a sole reference crop to estimate N_2 fixed by a forage legume, as they will be sampling soils of different $^{15}N/^{14}N$ ratios. In adopting the companion grass or non-fixing crop in a mixed pasture to estimate N_2 fixed by the forage legume it is assumed that no significant N transfer occurs from the legume to the non-fixing crop and that both the crops are sampling similar $^{15}N/^{14}N$ ratios over time.

Many reports have shown that forage legumes transfer N to associated non-legumes (Broadbent et al 1982; Bhaskar et al, 1984; Simpson, 1965). Broadbent et al (1982) therefore concluded that isotope dilution methods are not suitable for estimating N_2 fixed in grass-legume mixtures. However, other reports have shown that such N transfer does not occur or is not of significance (Vallis et al, 1967; Butler and Ladd, 1985a; Haystead and Marriott, 1979; Haystead and Lowe, 1977). Much of the evidence for N transfer has been obtained as a result of the lowered $^{15}N/^{14}N$ ratio in a non-fixing crop grown in association with a forage legume compared to the non-fixing crop grown alone (Fried et al, 1983), with the lowered ^{15}N composition being attributed to the transfer of fixed N of lower $^{15}N/^{14}N$ ratio to the associated grass. However, what has not been established in most of these studies is whether the non-fixing crops under the two cropping systems had identical growth (or N- uptake) patterns and were growing on soils with similar $^{15}N/^{14}N$ ratios (Vallis et al, 1967). Evidence in the literature suggests that they may have been growing on soils of different $^{15}N/^{14}N$ ratios as a result of, e.g. differential litter accumulation (Birch and Dougall, 1967; Vallis et al, 1977) or differences in mineralisation of native organic matter under the two crops (Birch and Dougall, 1967; Vallis et al, 1977; Broadbent and Nakashima, 1974), and the growth vigour (and thus possible N-uptake pattern) of the non-fixing crop may have been altered as a result of growing near a legume (Simpson, 1965; Vallis et al, 1967; Butler and Ladd, 1985b). These may help to explain why in some studies the ^{15}N enrichment in the non-fixing crop grown alone was lower instead of higher than that of the non-fixing crop in the mixture. Furthermore, lower ^{15}N enrichments in mixed legume-grass mixtures could be due simply to contamination of the separated grass roots by small amounts of legume root fragments (Butler and Ladd, 1985a).

As to the probability that non-fixing and fixing crops growing in association may be sampling soil of different $^{15}N/^{14}N$ ratios, the chances are not as high as when the reference and fixing crops are grown on separate plots. This is because although higher litter decomposition due to higher legume-litter turnover may result in a lowered $^{15}N/^{14}N$ ratio in soil under mixed pasture than under grass alone, the altered soil $^{15}N/^{14}N$ ratio, if homogeneous, is being sampled by both crops.

Sampling of plant material: It has been demonstrated that different plant parts (e.g. seed, herbage, crowns and roots) of crops grown on ^{15}N-enriched soil may contain N of different isotopic composition from each other (Ladd et al, 1981b; Rennie et al, 1978; Fried et al, 1983; Butler and Ladd, 1985a). This difference in enrichment has been cited as a problem in the ^{15}N- isotope technique for estimating N_2 fixed (Heichel et al, 1981; 1984). However, as pointed out by Fried et al, (1983), errors due to differences in ^{15}N enrichment can be minimised by sampling each of these plant parts with fairly uniform N-isotopic composition separately for ^{15}N determination and using the following equation to derive a weighted atom % ^{15}N for the whole plant:

$$WPAE = \frac{AE_{(a)} \times TN_{(a)} + AE_{(b)} \times TN_{(b)} + AE_{(c)} \times TN_{(c)}}{TN_{(a+b+c)}} \quad .....(10)$$

Where WPAE = weighted atom % ^{15}N excess
AE = atom % ^{15}N excess in different plant parts represented as a, b and c.
TN = total N in parts a, b and c

In small-seeded forage legumes, it is even uncertain if differences in densities of the small seeds and the rest of the plant are substantial enough to introduce significant errors in sampling the whole plant. Perhaps these two approaches need to be tested, since the whole plant approach avoids adding up errors from each of the different samples and demands less labour and cost for separation of plant parts and $^{15}N/^{14}N$ ratio analysis. Furthermore, although the evidence for the existence of differences in $^{15}N/^{14}N$ ratio in different plant parts is strong for N_2-fixing legumes, results obtained from the FAO/IAEA Biotechnology Laboratory in Seibersdorf, Austria (Zapata et al, unpublished data) show that, while ^{15}N distribution in pods and straw were dissimilar for either *Vicia faba* or nodulated soya bean, for non-nodulating soya bean and barley these parts were of similar N-isotopic enrichment. Also, Haystead and Lowe (1977) and Heichel et al (1981) have reported fairly uniform ^{15}N enrichments in shoots, roots and stubble of white clover and alfalfa, respectively. As a compromise, therefore, it may be advisable to perform preliminary N-isotopic analysis on different plant parts of crops used in an experiment and if the N-isotopic composition is fairly uniform, there will then be no need to continue splitting the different plant parts in the experiment as well as in subsequent ones. However, the problem may not arise in many forage legumes since, in most cases, these are harvested before seed production.

Most estimates of nitrogen fixation have been calculated on the basis of either herbage or above-ground plant parts (Williams et al, 1977; Phillips and Bennett, 1978; Heichel et al, 1984). In many grain legumes, roots or underground structures may not constitute a significant proportion of total dry matter, and therefore the error made by excluding roots may not be as serious as in forage legumes, some of which could have a large proportion of the total dry matter below ground (Heichel et al, 1981; 1984). In such cases, not only would the estimate of the total amount of N_2 fixed be inaccurate, but the proportion of N_2 fixed may be overestimated, since roots are known to have higher ^{15}N enrichments than foliage or seeds (Bergersen and Turner, 1983). In addition, for many perennial legumes the N stored in these underground structures and unharvested portions of foliage may, after decomposition, exert a significant effect on the dilution of the soil $^{15}N/^{14}N$ ratio. Errors in N_2-fixation estimates may thus result unless both the legume and its reference crop have similar amounts of carryover N, which is not likely under many circumstances. It is therefore advisable to estimate this stored N and make a correction for its effect on the isotopic composition of N at harvest, as suggested by Haystead and Lowe (1977), who proposed the following equation for correcting for the effect of carryover plant N.

$$\Delta N = Ep/(1-N_{R+o}/N_p) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(11)$$

where ΔN is the nitrogen uptake during the growing period, Ep is the measured ^{15}N enrichment of whole plants, N_p is the total nitrogen content of the whole plant at harvest and N_{R+o}

is the nitrogen in stubble, roots and nodules. In harvesting roots, special efforts have to be made to dig up as much of the roots as possible, since this could be a source of error, and since any soil N adhering to the roots could drastically alter the $^{15}N/^{14}N$ ratio in them thorough washing is recommended.

Forms and methods of incorporation of ^{15}N-labelled materials: Many different formulations of ^{15}N-labelled materials have been used to estimate N_2 fixation in grain and forage legumes. These include $(NH_4)_2SO_4$ (McAuliffe et al, 1958; Vallis et al, 1967; 1977; Haystead and Lowe, 1977; Phillips and Bennett, 1978), NH_4Cl (Williams et al, 1977; Witty, 1983), urea (Ham, 1978; Edmeades and Goh, 1979; Steele, 1983), residual ^{15}N in soil (Fried et al, 1983), organic residues (Fried et al, 1983; Boddey et al, 1984; Witty and Ritz, 1.84; Butler and Ladd, 1985a), oxamide (Witty and Ritz, 1984; Hauck, personal communication), as well as many others.

From the literature it seems that $(NH_4)_2SO_4$ has been most commonly used, although no explanation has been given for this preference. However, Vallis et al (1967) observed a greater uptake of N from $K^{15}NO_3$ than from $(^{15}NH_4)_2SO_4$ and suggested that ammonium would probably be better than the nitrate form of fertilizer when the aim is to have much of the tracer incorporated in the internal soil nitrogen cycle. On the other hand, nitrate is better when the objective is to minimise microbial transformation before uptake. According to Haystead and Lowe (1977), in order not to disturb the soil N cycle, labelled N should be added in a form already present in the soil. Much more work on comparing different ^{15}N-labelled fertilizers and materials for measuring N_2 fixation in different legume is needed, such as the rates of N release by different formulations and their influence on the declining soil $^{15}N/^{14}N$ ratio (Witty and Ritz, 1984), preferential uptake of different ionic forms of N by different crops and how they affect N_2-fixation estimates (Ledgard et al, 1985b). Slow-release formulations and ^{15}N-labelled organic matter offer great promise in N_2-fixation studies, since the $^{15}N/^{14}N$ ratio in the soil would remain more stable due to the rather slow release of a small but constant amount of N, which would probably lead to less errors between different reference crops and legumes attributable to differences in relative N-uptake profiles. This is supported by the finding of Butler and Ladd (1985a) that the inorganic N released within a 12-week period from each of 4 soils into which ^{15}N-labelled organic matter had been incorporated had approximately constant ^{15}N atom % enrichment. Similar results have also been reported by Legg and Sloger (1975) and Ladd et al (1981b). In such instances the isotopic enrichment of soil N taken up by legumes and non-fixing crops would be similar, irrespective of any mismatch in growth patterns or N-uptake profiles. Furthermore, Butler and Ladd (1985a) observed that the proportion of ^{15}N in the inorganic N released from ^{15}N-enriched materials was high enough to disregard isotopic discrimination effects during N uptake.

On the other hand, although Boddey et al (1984) did not get a constant ^{15}N enrichment of soil N until the fourth harvest in soil enriched with ^{15}N-labelled organic material, not only was the coefficient of variation of the first three harvests lower for this treatment, but also there was a closer agreement between the ^{15}N-uptake profiles of the nodulated and non-nodulated plants than when labelled inorganic fertilizer was applied.

Just as with the different forms, many methods of ^{15}N application have been used, including broadcast at planting (Ham, 1978), broadcast and incorporated 1 week before planting (Heichel et al 1981), sprayed or injected into soil as solution (Simpson, 1965; Vallis et al, 1967; Fried et al, 1983; West and Wedin, 1985; Broadbent et al, 1982) and banding (Fried et al, 1983). The greatest problems with the different methods of application may, however, be related to uniformity of fertilizer distribution in the soil and how each method affects the rate of release of ^{15}N (or tie-up in the soil colloid or organic matter). Certainly, surface application, unless followed by irrigation or rainfall, may lead to vertical gradients in the ^{15}N composition of soil which, if substantial, may make it crucial to have roots of reference and fixing crop at similar depth. Solution application has the advantage that small amounts of ^{15}N-labelled fertilizer (which would be difficult to distribute evenly on the soil surface) can be dissolved in a large volume of water and applied uniformly to cut down on spatial variability. Also, this approach makes it possible to mix fertilizers of different ^{15}N enrichments to obtain a homogeneous N- isotopic composition.

Unlike N_2-fixation studies in annual grain legumes, for which single doses of 15N-enriched fertilizer have been applied usually at planting, those involving forage legumes have often used equal-sized additions of small doses of ^{15}N fertilizer applied frequently, at short intervals (Catchpoole, 1983; Vallis et al, 1967; 1977; Haystead and Lowe, 1977). This may have the advantage that the $^{15}N/^{14}N$ ratio in the soil may be high at most periods of the plant's growth and may thus help to reduce errors due to the rapid decline in $^{15}N/^{14}N$ ratios that follows after the application of ^{15}N fertilizers (Fried et al, 1983; Heichel et al, 1984; Chalk, 1985). The ^{15}N enrichments of the inorganic fertilizers used on forage legumes have ranged from as low as 3 atom % ^{15}N excess (Phillips et al, 1983) to as high as 97.6% (Haystead and Lowe, 1977). Excessively high ^{15}N enrichments increase the cost of the experiment unnecessarily.

An experiment was set up in the FAO/IAEA Agricultural Biotechnology Laboratory in Seibersdorf, Austria, to test how different N rates, ^{15}N enrichments and frequency of fertilizer application affect estimates of N_2 fixation in alfalfa in consecutive harvests of an alfalfa-ryegrass mixture over a 2-year period. The treatments, which are represented schematically in Table 1, comprised:

1. Treatment 1, in which urea of high ^{15}N enrichment (50 atom % ^{15}N excess) was applied at a low rate (5 kg N/ha) at establishment and then to a new subplot after each

harvest.

2. Treatment 2, where urea of low ^{15}N enrichment (5 atom % ^{15}N excess) was applied at a low rate (5 kg N/ha) to the same plot at planting and then after each harvest.

3. Treatment 3, which consisted of the application of a low rate of N fertilizer (5 kg N/ha) of a moderately high ^{15}N enrichment (16.65 atom % ^{15}N excess) once a year (instead of twice a year as in Treatments 1 and 2) to the same subplot.

4. Treatment 4, in which a high initial dose of urea of low ^{15}N enrichment (45 kg N/ha, 5.73 atom % ^{15}N excess) and none thereafter during the 2 years.

Table 1. Effect of ^{15}N enrichment, fertilizer level and method of application on N_2 fixation estimates.

Treatment number	Subplot	Atom % ^{15}N excess	--------kg N/ha-------- 1st Year T_1	T_2	2nd Year T_3	T_4
1	i	50	5*	5	5	5
	ii	50	5	5*	5	5
	iii	50	5	5	5*	5
	iv	50	5	5	5	5*
2	i	5.73	5*	5*	5*	5*
3	i	16.65	5*	5	5*	5
4	i	5.73	45*	0	0	0

* = ^{15}N-labelled fertilizer applied.

The results showed that all treatments gave similar estimates of N_2 fixation, except Treatment 4, in which the high initial rate of N reduced N_2 fixation (Hardarson, Danso and Zapata, unpublished). Since the cost of 15N-enriched inorganic fertilizers rises disproportionately as the percentage of ^{15}N increases, the best treatment from this study would be Treatment 2 (application of 5 kg N/ha of a 5 atom % ^{15}N excess fertilizer (0.025 g $^{15}N/m^2$) at establishment and also after each harvest), followed by one in which 5 kg N/ha of 16.65 atom % ^{15}N excess urea is applied at establishment and then after every other harvest.

Further trials by participants of the FAO/IAEA Co-ordinated Research Programme (CRP) on the use of nuclear techniques in pasture management were carried out (Table 2).

Table 2. Schematic diagram of effect of methods of ^{15}N fertilizer application on estimates of nitrogen fixation.

Treatment number	Subplot	Atom % 15N excess	Harvest 1	2	3	4	etc.
1	i	5	5	5	5	5	
	ii	5	5	5*	5	5	
	iii	5	5	5	5*	5	
	iv	5	5	5	5	5*	
2	i	5	5*	5*	5*	5*	
3	i	10	5*	5	5*	5	

* = ^{15}N labelled fertilizer applied.

The preliminary results (unpublished) have confirmed that 5 kg N/ha of 5 atom % ^{15}N-enriched fertilizer is enough to measure N_2 fixed in forage legumes. The three different approaches were used (i) application at planting and then to a new subplot after each harvest; (ii) application of ^{15}N fertilizer at planting and then after each harvest to the same subplot; (iii) application at planting, second harvest and then after every second harvest to the same subplot. Each gave similar estimates of the proportion of N derived from fixation. Most of the forage legumes studied fixed in excess of 70 % of their total N requirements. Applying ^{15}N fertilizer to the same subplot has the advantage of confining the isotope experiment to a small area. A major disadvantage, however, is that the isotopic-derived values such as % Ndff and % fertilizer utilisation cannot be reliably estimated after the first harvest because of the unknown contribution from carryover and residual ^{15}N in previous applications.

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THE POTENTIAL CONTRIBUTION OF SOME FORAGE CROPS TO THE NITROGEN BUDGET AND ANIMAL FEED IN THE SUDAN GEZIRA FARMING SYSTEM

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ABSTRACT

The ability of four forage legumes (*Dolichos lablab, Phaseolus trilobus, Clitoria ternata* and *Cajanus cajan*) to fix atomospheric nitrogen in sole cropping and in association with sorghum (*Sorghum vulgare*) was assessed using the ^{15}N technique. Dry-matter and total N yields were determined and the potential contribution of each forage crop to the N budget of the Gezira farming system was assessed. Dry matter yields ranged between 3.3 and 7.0 t/ha per cut, and total N yield between 62 and 140 kg N/ha. Mixed cropping greatly reduced the dry-matter and total N yields of *P. trilobus, Clitoria ternata* and *Cajanus cajan*, mainly because of the smothering effects of the sorghum. The legumes fixed 60 to 80% of their N requirements, although there was considerable seasonal variation. The total amount of N fixed was equivalent to 55 to 110 kg N/ha per cut. In one out of the three seasons mixed cropping with sorghum reduced the proportion of the N requirement that was fixed by some of the legumes compared with the legumes in sole cropping. It was not clear whether this was due to the depressing effect of the sorghum on the legume, or whether fixed N was transferred to the sorghum. Residual NO_3-N varied significantly among the forage crops, and the highest residual value of 26 ppm NO_3-N was equivalent to the amount of NO_3-N mineralised in an equal period of fallow.

INTRODUCTION

The beneficial effects of a legume in an unfertilized rotation in the Gezira cropping system in Sudan have long been recognised. Also, with the recent need for integration of livestock into the farming system, fodder is becoming more valuable. Attempts have been made at the Gezira Research Station to determine the nitrogen-fixing ability of different forage legumes and their effects on yields of following crops using conventional methods (Musa and Burhan, 1974). The results showed that forage legumes tested were active fixers of atmospheric nitrogen, but data reported were inconsistent. It was also shown that legumes had some beneficial effects on subsequent crops.

The yield of cotton in Gezira is markedly influenced by the level of NO_3-N in the soil. However, the effects of heavy manuring on soil NO_3 and crop production were shown to be largely confined to the year of application, and no accumulations of nitrates could be detected (Ayoub, 1985).

The objectives of this work were to use the ^{15}N isotope technique to reassess the ability of different forage legumes to fix atmospheric nitrogen, and to use these and other data to calculate the potential contribution of each forage crop to the N budget of the Gezira cropping system.

MATERIALS AND METHODS

Forage crops (*Dolichos lablab, Phaseolus trilobus, Clitoria ternata, Cajanus cajan,* and *Sorghum vulgare*) were grown in monoculture or in a mixed crop with the legume and sorghum planted in the same hole. The experiment was conducted at the Gezira Research Farm, Sudan, between 1982/83 and 1984/85 on a heavy, alkaline clay low in N and organic matter. Plot size was 4.2 m x 6 m, with a subplot of 1.0 m x 1.8 m at the end of each plot to which ^{15}N was applied. The rest of the plot received ordinary urea at the same rate as the isotope subplot. Plants were sown in early July on ridges 60 cm apart and 20 cm between plant holes with four plants per hole. The plots were arranged in a randomised block design with five replications. Sorghum received urea at the rate of 100 kg N/ha while the legumes and legume-sorghum combinations received urea at the rate of 20 kg N/ha. In the isotope subplots the ^{15}N atom excess of urea was 1.0% in the former and 5.0% in the latter. A basal dressing of 51 kg P/ha was given as triple superphosphate to all plots. All legumes and legume-sorghum plots were inoculated with the appropriate rhizobia two weeks after sowing. The plots were irrigated with water from the Blue Nile once every 2 weeks, and were hand weeded whenever necessary.

Determinations of dry-matter yield, total N yield and $^{15}N/^{14}N$ ratio assay were carried out at harvest (12 weeks after sowing). Soil samples were taken 6 months after harvest from the root zone in each plot and from an adjacent fallow strip for comparison of the nitrification of the residual N during an incubation period of 6 weeks at set moisture and room temperature.

The International Atomic Energy Agency, Vienna, supplied the ^{15}N-labelled urea and assayed the $^{15}N/^{14}N$ ratio in the plant samples.

RESULTS AND DISCUSSION

Dry-matter and nitrogen yields

Table 1 shows the dry-matter (DM) yields, N contents and total N yields of different forage crops grown in monoculture or associated with sorghum in 1:1 ratio. The DM yields in monoculture varied between 3.3 and 7.0 t/ha per cut. Three cuts are possible from these crops but for the purpose of this study only one cut was taken. The highest DM yield was produced by sorghum followed by lablab and trilobus and least by cajanus and clitoria. Clitoria had the highest N content followed by trilobus, lablab and cajanus. The N content of sorghum was less than 1.0% and sorghum gave the lowest

Table 1. Dry-matter yields, percent N and total N yields of five forage crops grown in monoculture or in 1:1 mixture with sorghum, Gezira (means of two seasons).

Crop	Dry matter (t/ha)	Percent N	N yield (kg/ha)
Monoculture			
Sorghum	7.0	0.90	62.1
Lablab	5.4	2.53	139.1
Trilobus	4.9	2.82	138.2
Clitoria	3.3	3.10	102.1
Cajanus	3.5	2.08	77.3
Mixed cropping			
Sorghum	3.9	0.85	32.3
Lablab	2.1	2.61	54.2
Total	6.0		86.5
Sorghum	4.9	0.78	37.7
Trilobus	1.0	2.73	27.3
Total	5.9		65.0
Sorghum	4.9	0.86	41.2
Clitoria	0.6	2.67	15.1
Total	5.5		56.3
Sorghum	4.7	0.79	36.3
Cajanus	0.9	2.21	18.9
Total	5.6		55.2

total N yield despite its high DM yield. The total N yields of lablab and trilobus were appreciably high, followed by clitoria and cajanus.

Lablab and sorghum competed well with each other for light and nutrients in the mixed stand, producing a good total DM yield with moderate protein content. Trilobus, clitoria, and cajanus were poor competitors with sorghum and produced less than 42% of their monoculture yields. As a result the N yields of their mixed crops with sorghum did not exceed that of sorghum when grown alone. Further work is being carried out to determine the sorghum-clitoria mixture that will produce the optimum combination of DM and total N yields.

Biological nitrogen fixation

The percentage of total N in the legumes derived from fixation of atmospheric N (% Ndf fix) was determined in the monoculture by the isotopic A value method since the legume and the sorghum received different rates of ^{15}N fertilizer. Where legumes were grown in association with sorghum, and hence both crops received the same rate of ^{15}N fertilizer, % Ndf fix was assessed using the simpler formula:

$$\% \text{ Ndf fix} = 100 \left(1 - \frac{^{15}N \text{ a.e. in legume}}{^{15}N \text{ a.e. in sorghum}} \right)$$

where a.e. is percent ^{15}N atom excess in the plant tissue. Both methods seem to give reliable results.

Mean % Ndf fix of the four legumes (Table 2) was 85% in 1983/84 and 60% in 1984/85. Trilobus, lablab and clitoria were the most active fixers while cajanus was the poorest, especially in 1984/85. In 1983/84 % Ndf fix was the same whether the legumes were grown in monoculture or in association with sorghum, while in 1984/85 it was about 30% lower in the mixed crops than in monoculture, clitoria showing the largest reduction when grown in association with sorghum. It is difficult at this stage to determine whether this low value in mixed cropping was due to sorghum depressing legume growth or due to the transfer of fixed nitrogen from the legume to sorghum. If there is transfer of fixed nitrogen from the fixer to the non-fixer the ^{15}N a.e. of the non-fixer will approach that of the fixer and hence percentage apparent N fixation will be low.

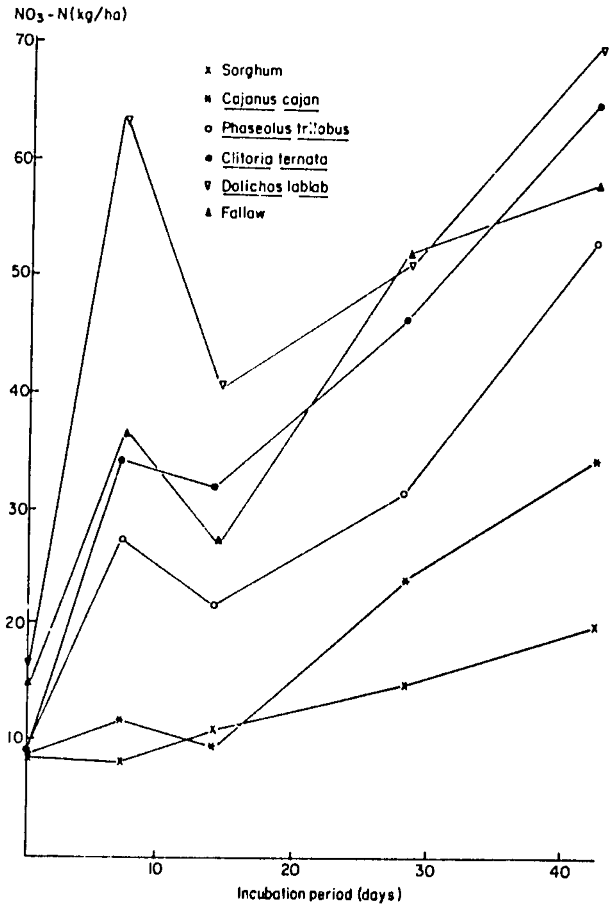
Table 2. Percent N derived from fixation by different forage legumes when grown in monoculture or associated with sorghum, Gezira, 1983/84 and 1984/85.

Crop	Percent N 1983/84	Percent N 1984/85	Mean % N
Monoculture			
Lablab	86	61	74
Trilobus	90	71	81
Clitoria	86	62	74
Cajanus	77	42	60
Mean	85	59	72
Mixed cropping			
Lablab and sorghum	82	46	64
Trilobus and sorghum	89	64	77
Clitoria and sorghum	78	11	45
Cajanus and sorghum	80	34	57
Mean	82	39	61

Nitrification of residual soil nitrogen

Figure 1 shows the release of NO_3-N during the incubation of soil samples taken from the root-zone of different forage crops 6 months after harvest. The NO_3-N level before incubation was about 8 kg/ha in the sorghum, cajanus, trilobus, and clitoria plots and 18 kg/ha in the lablab and fallow plots. After one week of incubation NO_3-N in soil from

Figure 1. *Nitrate-N release during incubation of soil samples from the root zone of different forage crops 6 months after harvest.*



trilobus, fallow, and clitoria plots exceeded 24 kg/ha, and in the soil from the lablab plot exceeded 60 kg/ha. After one more week of incubation the NO_3-N level dropped by about one-third of its previous level in the lablab, clitoria, fallow, and trilobus soils. This was probably due to the proliferation of microbial growth, which subsided soon after, resulting in steady NO_3-N release afterwards. Little NO_3-N was released in the sorghum and cajanus soils during the first 2 weeks of incubation, and rates of nitrification in these soils were lower throughout incubation than in the other soils.

At the end of the incubation period (42 days), the residual NO_3-N levels were between 53 and 70 kg/ha in the trilobus, fallow, clitoria, and lablab plots, while in the sorghum and cajanus plots the NO_3-N levels were only 20 and 35 kg/ha, respectively. It must be remembered here that the sorghum crop received 100 kg N/ha and each of the legumes received 20 kg N/ha at sowing. A very simplified view of N input-output of each forage crop is discussed in the following section.

Soil nitrogen budget after forage crops

The Gezira soil can supply an average crop with about 60 kg N/ha in a season. This N comes mainly from the mineralisation of the indigenous soil organic N, and possibly from non-symbiotic nitrogen fixation. This figure was taken as the basic value in these calculations, regardless of the differences that may occur in the rhizosphere of the different forage crops.

Lablab and trilobus contributed about 110 kg N/ha to the soil N budget through biological nitrogen fixation while clitoria and cajanus contributed 75 and 55 kg N/ha, respectively. The end-of-season contribution of the different forage crops to soil N through the root system, including nodules, ranged between 10 and 20 kg N/ha (Musa and Burhan, 1974). These values underestimate the actual amount of N contributed, since some of the nodules and fine roots could not be collected. The total non-harvestable N, which was found by subtracting N harvested from total N input, was 108 kg N/ha for sorghum and around 70 kg N/ha for the legumes. The corresponding differences between these values of non-harvestable N and the residual NO_3-N values, already shown in Figure 1, indicate the non-recoverable N in the system. Sorghum and, to some extent, cajanus gave high values of non-recoverable N. The non-recoverable N was presumably either in the form of organic N that was not readily decomposable in the soil system or had been lost to the atmosphere as gaseous N. There is evidence that considerable amounts of N are lost from the Gezira soil system through volatilisation of ammonia leading to low recoveries of fertilizer N (Jewitt, 1942). The efficiency of urea-N use by sorghum has been found to be around 23% (Ayoub, 1986). It is therefore reasonable to believe that at least 50% of the N that was not recoverable as NO_3-N from the sorghum and cajanus plots may have been lost as gaseous N, resulting in nitrogen deficits of about 45 and 20 kg N/ha in the sorghum and cajanus plots, respectively. Nitrogen deficits, if any, in the lablab, clitoria and trilobus plots were negligible.

The figures in Table 3 were calculated on the assumption that the crops would be cut and removed from the land for fodder. If these forage crops were grazed *in situ* a considerable part of the harvested N could be recycled to the soil system through the grazing animals.

SUMMARY AND CONCLUSIONS

1. The legumes under study derived about 60 to 80% of their total N needs from N fixation. The amount of N fixed was equivalent to about 55 to 110 kg N/ha per cut.
2. Mixed cropping of sorghum in 1:1 ratio with legumes other than lablab resulted in lower total DM and N

yields than growing each crop alone, due to the smothering effects of sorghum.

3. An account of the soil N balance sheet after one cut of the forage crops shows the possibility of lablab and clitoria, and to some extent trilobus, in maintaining soil fertility. If these crops were grazed *in situ* a much higher N gain could be achieved.

Table 3. Potential contribution of different forage crops to the nitrogen budget of Gezira soil.

	Sorghum	Lablab	Trilobus	Clitoria	Cajanus
N input (kg N/ha)					
Mineralisable N	60	60	60	60	60
Fertilizer N	100	20	20	20	20
Biologically fixed N	0	107	115	75	55
Root debris N	10	20	15	20	15
Total	170	207	210	175	150
N output(kg N/ha)					
Harvested crop N	62	139	138	102	77
N non-harvestable (1-2)	108	68	72	73	73
Residual NO_3-N (see Figure 1)	20	70	53	65	35
N not recoverable as NO_3-N (4-3)	-88	+2	-19	-8	-38

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PRELIMINARY STUDIES ON THE SYMBIOTIC ASSOCIATION BETWEEN RHIZOBIUM AND LEUCAENA LEUCOCEPHALA (LAM) DE WITT. IN ZAIRE

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ABSTRACT

The symbiotic relationship between rhizobium and *Leucaena leucocephala* was studied using a strain of rhizobium isolated from the rhizospheric soil of a leucaena tree growing near the Regional Centre for Nuclear Studies at Kinshasa.

The isolate was purified on Yeast Extract Mannitol Agar and used to inoculate seedlings of a local cultivar of *L. leucocephala* grown in vermiculite moistened with N-free Fahraeus medium. Efficient nodules were observed 38 days after inoculation. The fresh weight of inoculated plants was 240% higher than that of the uninoculated control plants. The leaves of the uninoculated plants showed symptoms of N deficiency.

In a second experiment, three cultivars of *L. leucocephala* (local, Peru and Cunningham), two cultivars of *Glycine max* (local and Amsoy) and a local cultivar of *Arachis hypogaea* were inoculated with *R. japonicum* sp. CB 756, *Rhizobium* CB 81, the local isolate and a peat-based inoculum for leucaena. The broad-spectrum *Rhizobium* CB 756, used in Australia to inoculate most of the cowpea group of legumes, nodulated only *Arachis hypogaea*, while strain CB 81, the local isolate and the peat-based inoculum nodulated only leucaena.

In an experiment with two different soils, beneficial effects were observed when the local cultivar of *L. leucocephala* was inoculated with the local isolate. Fresh

weight of inoculated plants was 140 % higher than that of the uninoculated control.

Biochemical analysis of leaves and seeds showed that the local cultivar of *L. leucocephala* was rich in proteins and other nutrients. Antitrypsic factors were also present but were inactivated by heating at 97 ^{o}C for 2 hours or autoclaving at 120 ^{o}C for 30 minutes.

INTRODUCTION

Leucaena species belong in the subfamily Mimosoideae of the Leguminoseae. They are widely used in the tropics as a shade plant, for erosion control, for fuel and as a browse crop. As a forage crop, leucaena has yielded upto 20 t DM/ha per year. Alfafa (*Medicago sativa*) yields more green forage than leucaena but the feeding value of the two are about equal (USAID, 1981).

Leucaena is rich in protein and is an excellent forage for animals and is also eaten by humans. In Australia, cattle fed on a diet of 100% leucaena gain up to 1 kg per animal per day and can be fed at this level about 4 months. In Asia and Latin America, the slightly better leaves, flowers and young pods are eaten by humans (Brewbaker and Styles, 1982).

The use of leucaena to maintain soil fertility has been documented (Prussener, 1982; Parera, 1982; Kovitradhi and Yantasath, 1982; USAID, 1981). However, not all soils contain the correct strain nor the necessary amount of rhizobium for effective N fixation by leucaena (Halliday and Somasegaran, 1982).

This paper presents the findings of preliminary studies of the symbiotic relationship between rhizobium and a local variety of *Leucaena leucocephala* in Zaire, which were conducted in order to elucidate rhizobium strain affinities with local species of leucaena.

MATERIALS AND METHODS

Isolation, purification and culture of bacteria

Indigenous rhizobia were isolated both from the rhizospheric soil and directly from nodules of leucaena seedlings, according to the method of Vincent (1970).

Data on the bacteria used in this investigation and their origins are given in Table 1. The isolates were maintained on Yeast Extract Mannitol (YEM) agar slants at 4 ^{o}C. To provide inoculant, bacteria were grown in YEM liquid medium for 4 days for the fast-growing strains and for 7 days for the slow-growing ones.

Plant material

Three cultivars of *L. leucocephala* were used to determine rhizobium-legume compatibility: a local cultivar growing spontaneously in the surroundings of CREN-K and the varieties Peru and Cunningham, supplied by CSIRO, Australia. Two cultivars of *Glycine max* (local and Amsoy) and a local cultivar of *Arachis hypogaea* were also tested. The effectiveness of the nodules was tested only on the local cultivar of *L. leucocephala*.

Tube experiment

Plants were grown in glass tubes (200 mm x 35 mm) containing 15 g of vermiculite moistened with 60 ml of nitrogen-free Fahraeus medium (Vincent, 1970).

Seeds of *Glycine max* and *Arachis hypogaea* were surface-sterilised with $HgCl_2$ 0.2% according to the method of Vincent (1970). Seeds of *L. leucocephala* were soaked in hot water (80 ^{o}C) for 5 minutes before being surface-sterilised. The seeds were germinated and the seedlings transferred aseptically to the sterilised glass tubes when the radicles

Table 1. Rhizobium strains used.

Strain	Origin	Characteristics
Rhizobium japonicum CB1809	CSIRO, Australia	Recommended for soya bean inoculation (Date, 1969)
Rhizobium sp. CB756	CSIRO, Australia	Recommended for inoculation of tropical legumes (Date, 1969)
Rhizobium sp. CB81	Plant Patholon Konedon, Papua New Guinea	Recommended for inoculation of *L. leucocephala* in acid soils (Diatloff, 1973).
Rhizobium sp. CREN-K	CREN-K collection of rhizobia	Indigenous rhizobi from a nodule of a local *L.leucocepha* (this work).
Peat-based inoculum	CSIRO, Australia	Inoculum for *L. leucocephala*

were about 1 cm long. The tubes were then inoculated with 5 ml of a rhizobium culture, providing about 5×10^9 rhizobia/tube. In the case of the solid inoculum, 1 g of peat was placed close to the young radicle. Uninoculated controls were treated with 5 ml of sterile YEM. When the seedlings reached the top of the culture medium, the vermiculite was covered with a layer of paraffined sand, prepared as described by Bonnier and Brackel (1969). Four tubes were used for each inoculation treatment and control. The experiment was arranged in a completely randomised design and the tubes were watered as required with sterile Fahraeus medium or sterile distilled water.

Pot experiment

The nitrogen-fixing abilities of the different rhizobium strains were evaluated on the local cultivar of *L. leucocephala* in 15 cm diameter x 15-cm-deep pots containing 1200 g of soil taken from the surroundings of CREN-K or from a field at Ndjili (30 km from CREN-K). Pots were covered with aluminium foil and sterilised in a forced air oven at $180^{o}C$ for 4 hours. Six pregerminated seeds of leucaena were planted in each pot; seedlings were removed after emergence to leave four plants per pot. Treatments compared were inoculated plants and uninoculated controls, with or without N. Each treatment was replicated three times in a completely randomised design. Pots were inoculated with 100 mg of a vermiculite-based inoculum prepared in our laboratory, containing 2.4×10^{10} rhizobia/g of moist vermiculite.

After germination, all the pots were placed outside under natural conditions of light, temperature and humidity. The pots were watered as required with non-sterile tap water. Nitrogen was added to pots one week after planting as an aqueous solution of KNO_3 at a rate of 100 kg N/ha.

Statistical analyses

Results of tube and pot experiments were subjected to analysis of variance and the means were compared using the new Duncan multiple range test (Dagnelie, 1975).

Chemical analyses

Chemical analyses were performed only on leaves and seeds of the local cultivar of *L. leucocephala*. Protein content was determined by the Kjeldahl method as modified by Villegas (1971). The ash content was determined according to Onyembe et al (1980b).

The Ca, Mg and P contents were determined according to the method of Didier de St. Amand et Cas (1967). Micronutrient contents (Mo, Cr, Zn, Fr, Co, Se, Na, Mn) were determined after neutron activation in the Triga Mark II reactor of the Regional Center for Nuclear Studies at Kinshasa. Lipids were extracted by the soxhelt method using ether as the solvent and the amount of lipids determined as the difference of weight before and after delipidation (Kabele et al, 1975; 1977).

RESULTS AND DISCUSSION

Isolation, purification and characterisation of isolates from leucaena nodules

The bacteria colonies on agar were whitish, convex, circular with regular contour, viscous and stuck easily to the inoculating loop. The colonies grew quickly and acidified the Wright agar medium containing bromothymos blue. The isolate did not absorb Red Congo dye. With a few exceptions, this property distinguishes between rhizobia and other bacteria (Barbara and Thomas, 1983).

Nodulation of *L. leucocephala*

Tube experiment: Thirty-eight days after inoculation, efficient root nodules (13 nodules per plant on average) were observed on inoculated plants, whereas uninoculated plants were without nodules. The nodules were elongated and measured 4 to 5 mm long and 1.5 to 2 mm wide. The inside of the nodules was dark red.

There were significant morphological differences between inoculated and uninoculated plants. The uninoculated plants were smaller than the inoculated plants and had yellowish leaves, whereas the leaves of the inoculated plants were dark green. Nodule numbers and plant fresh weights are shown in Table 2.

Table 2. Effect of inoculating a local variety of *Leucaena leucocephala* with a local isolate of rhizobium on nodule numbers per plant and plant fresh weight 38 days after inoculation.

Treatment	Number of nodules per plant	Plant fresh weight (mg)
Uninoculated	0	128
	0	102
	0	76
Inoculated	12	317
	14	352
	10	315
	9	310
	16	388
	15	388
	12	345

Pot experiment: Uninoculated plants did not nodulate and gave smaller fresh-weight yields than inoculated plants even when 100 kg N/ha was applied (Table 3). The fresh-weight yield of inoculated plants was more than double that of uninoculated plants in both the low-N soil (CREN-K, 0.02% N) and the N-rich soil (Ndjili, 0.23% N).

As in the tube experiment the internal colouration of the nodules was dark red, suggesting the presence of leghaemoglobin, which is related to nitrogen fixation efficiency (Bergersen, 1966; Bonnier and Brackel, 1969; Vincent, 1970).

Table 3. Effects of inoculation (local rhizobium isolate), N fertilizer (100 kg N/ha) and soil type on nodulation and fresh and dry weights per plant of a local variety of *Leucaena leucocephala* 55 days after sowing in a pot trial.

Soil	Treatment	Nodules per plant	Fresh wt per plant (mg)	Dry wt. per plant (mg)
CREN-K	Uninoculated (Control)	0	1425	275
		0	975	225
	Uninoculated + 100 kg N/ha	0	2825	550
		0	1750	325
		0	1400	250
	Inoculated	10	3150	675
		7	2550	550
Ndiili soil	Uninoculated (Control)	0	1075	550
		0	1400	250
		0	1475	275
	Inoculated	6	2975	675
		10	3275	725

Study of local leucaena isolate specificity

Only the isolate obtained from the local variety of *Leucaena leucocephala*, strain CB 81 and the Australian peat inoculum for leucaena formed root nodules on the three leucaena cultivars used in the experiment. In each case, the fresh-weight yield of nodulated leucaena plants was more than double that of the non-nodulated plants. These results indicate that the local rhizobium isolate is effective in forming nodules and fixing N.

Biochemical studies

General analyses: The biochemical composition of the local variety of leucaena was similar to that found by other workers (see NAS, 1977; Riviere, 1978). The seeds contained more protein than the leaves (36.13 vs 25.56%), while leucaena leaves contained nearly twice as much protein as the leaves of *Stylosanthes guianensis* (Table 4).

Compared with other local legumes, leucaena seeds contained much less lipids than *Glycine max* and *Psophocarpus tetragonolobus* but more than *Phaseolus vulgaris* and *Sphenotylis sternocarpa*. Carbohydrate content was similar to that of *P. vulgaris* and *S. sternocarpa* seeds, and higher than that of *P. tetragonolobus* and *Glycine max* (Table 5).

Anti-trypsic activity: Leucaena contains antinutritive factors, such as trypsin inhibitors and mimosine, which reduce its feeding value. Antitrypsic activity was observed in leucaena seeds in this study, but it was found that this could be eliminated by heating the seeds at 97°C for 2 hours or by autoclaving the seeds at 120°C for 30 minutes, as previously reported for other legumes (Onyembe et al, 1980a; Gillespie et al, 1981).

Table 4. Biochemical composition of the leaves of a local variety of *L. leucocephala* and *Stylosanthes guyanensis* leaves.

	L. leucocephala (local) leaves (% DM)	*S. guianensis* leaves (% DM)
Crude protein	25.56	12.9
Fats	1.81	2.8
Carbohydrate	66.40	75.9
Ash	6.23	8.4
Ca	0.56	1.25
Mg	0.20	0.21
P	0.22	0.24
K	1.31	1.44
Fibre	20.3	32.2

Source: Riviere (1978).

Table 5. Biochemical composition of *Leucaena leucocephala* seeds compared with that of other legumes grown in Zaire.

Species	Moisture	Crude protein	Fats	Carbo-hydrates	Fibre	Ash
	% DM					
L. leucocephala	27.31	36.13	2.27	57.81	15.6	3.79
S. stenocarpa	11.14	21.32	1.64	62.28	7.6	3.32
P. tetragonolobus	8.70	29.8-40.0	16.80	39.00	4.1	4.40
Glycine max	10.00	37.1-40.8	17.00	35.80	6.0	5.30
P. vulgaris	10.00	20.3	1.2	69.9	5.0	4.79

Source: Onyembe et al (1982).

CONCLUSIONS

Leucaena was found to be nodulated only by strains of rhizobia that were isolated from *Leucaena* species. The broad-spectrum cowpea strain of rhizobium , CB 756, which nodulates most tropical legumes, failed to nodulate the three cultivars of leucaena used in this study. It was found that efficient nodulation more than doubled the fresh weight yield of leucaena compared with the non-nodulated control plants.

It was also found that leucaena contains a large proportion of crude protein and other nutrients, and that the antitrypsic factor presnt could be inactivated by heat treatments.

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COMPETITION FOR NITROGEN BETWEEN A MAIZE CROP AND FORAGE LEGUME INTERCROPS IN A WET-DRY TROPICAL ENVIRONMENT

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ABSTRACT

Growth and yield of maize as a sole crop was compared with that of maize with intercrops of *Alysicarpus vaginalis, Stylosanthes hamata* cv. Verano, or *Centrosema pascuorum* under conditions in which soil water was adequate prior to physiological maturity of the crop. Data from three seasons are presented. In the first season, when only one N rate was used with a range of legume densities, maize yield varied inversely with legume yield. In the other two seasons N rate was varied, and ^{15}N was used to obtain more information on the competitive relationships between the components of the intercropping systems. Results show that when conditions are good for establishment and early growth of the legumes, competition between the legume intercrop and maize occurs. This effect was greatest at low N rates and less with Verano stylo than with *A. vaginalis*. There was never any evidence of a postive contribution by any of the legumes to the N economy of the maize.

Legume seed production, essential for regeneration of the legume in the cropping system being studied, varied with species and seasonal conditions.

INTRODUCTION

This research is part of a project on the feasibility of a no-tillage, ley farming system for the semi-arid tropics of northern Australia (McCown et al 1985). When a cereal crop is sown after a legume phase in such a system one can either prevent establishment of the legume from seed using pre-emergence herbicides or allow the legume to grow as an understory in the cereal crop. Advantages of the latter approach include (a) improvement of the quality of residues for cropland grazing during the dry season, (b) provision of additional seed for subsequent legume pasture establishment, and (c) protection against soil erosion by the legume cover.

Legumes in close association with nitrophilous crops have increased crop production (Nair et al 1979; IITA 1980; Waghmare and Singh, 1984), but other studies have shown that legumes can compete for soil N with the associated crop and reduce its grain yield (Kurtz et al 1952a,b; Enyi, 1973; Wahua, 1983). Our research aims to elucidate the interactions between a maize crop and a forage legume understory under (a) nitrogen-limiting conditions and (b) under water-limiting conditions, so that the requirements for maintenance of high intercrop maize yields can be defined. This paper reports findings on the N aspects when water was non-limiting.

MATERIALS AND METHODS

All experiments were carried out at CSIRO's Katherine Research Station, northern Australia, latitude 14^{o}S, longitude 132^{o}E. The soil is a red earth (Oxic Paleustalf) (Williams et al 1985). Fertilizer was applied so that all elements except N were non-limiting. Three well-adapted legumes differing in growth habit and maturity were used as intercrops. All behave as annuals in this climate. *Stylosanthes hamata* cv Verano is semi-erect and is intermediate in maturity; *Alysicarpus vaginalis* (Martin and

Torssell 1974) is semi-erect and the earliest maturing; *Centrosema pascuorum* has twining stems and is late maturing (Clements et al, 1983).

In all experiments maize was sown at a row spacing of 75 cm. Mid-season cultivars that reached anthesis approximately 50 days after sowing and reached maturity after approximately 100 days were used. Legumes were sown at the same time as the maize, and all plots were hand weeded.

Experiment 1 was designed to test whether a legume understory reduced maize grain yield. In the 1979/80 wet season the maize cultivar DeKalb XL99 was sown to give a population of 45,000 plants/ha. Legumes were broadcast at rates shown in Table 1. The design was a split plot with legume species as main plots and seeding rates as subplots. Subplot size was 3 m x 5 m and there were two replicates. Ammonium nitrate fertilizer was applied at 75 kg N/ha broadcast 2 weeks before sowing and 30 kg N/ha broadcast at sowing. The crops were not irrigated and the rate of N applied was expected to give maize grain yields of 5-6 t/ha. At physiological maturity maize grain yield was measured from an area of 4.5 m^2 and legume dry matter yield from two 0.25 m^2 areas. A further 0.5 m^2 of legume was sampled at legume maturity when seed yield was also measured.

Table 1. Legume seeding rates, Experiment 1.

	Seeding rate (kg/ha)			
Species	Density 1	Density 2	Density 3	Density 4
S. hamata	1	8	30	180
A. vaginalis	1	6	20	80
C. pascuorum	2	10	35	120

Experiment 2 was carried out in the 1982/83 wet season and compared maize (cv. Sergeant) grown as a sole crop with maize intercropped with *A. vaginalis, S. hamata,* or *C. pascuorum*. Maize population was 60,000 plants/ha and to simulate a natural situation legume seed was broadcast on appropriate plots at rates sufficient to give stands of approximately 1.5 million plants/ha. Water deficits were prevented by a supplementary irrigation schedule based on pan evaporation measurements. Three rates of N were applied as ammonium sulphate: low - 25 kg N/ha broadcast at sowing; medium (marginally adequate) - 50 kg N/ha broadcast at sowing; and high - 50 kg N/ha broadcast at sowing, 40 kg N/ha banded 25 days after sowing and 50 kg N/ha broadcast at silking. Rain after the first broadcast application washed the fertilizer into the soil. The experiment was a split plot design with N rates as main plots, and legume species as subplots. There were two replicates with sub plot size of 6 m x 6 m. Ammonium sulphate enriched with ^{15}N was applied in solution to microplots within the low and medium N treatments at sowing at a rate of 50 mg $^{15}N/m^2$. Microplot size was 2.0 m x 1.25 m with a sample area of 1.5 m x 0.75 m. At maize maturity total legume yield, total maize yield (including senescent leaves), maize grain yield and components of yield were measured. Sample size for maize was 11.25 m^2, and 2.25 m^2 for the legume. Plants from the microplots were also harvested at maize maturity. All samples were analysed for total N, and those from the microplots were also analysed for ^{15}N.

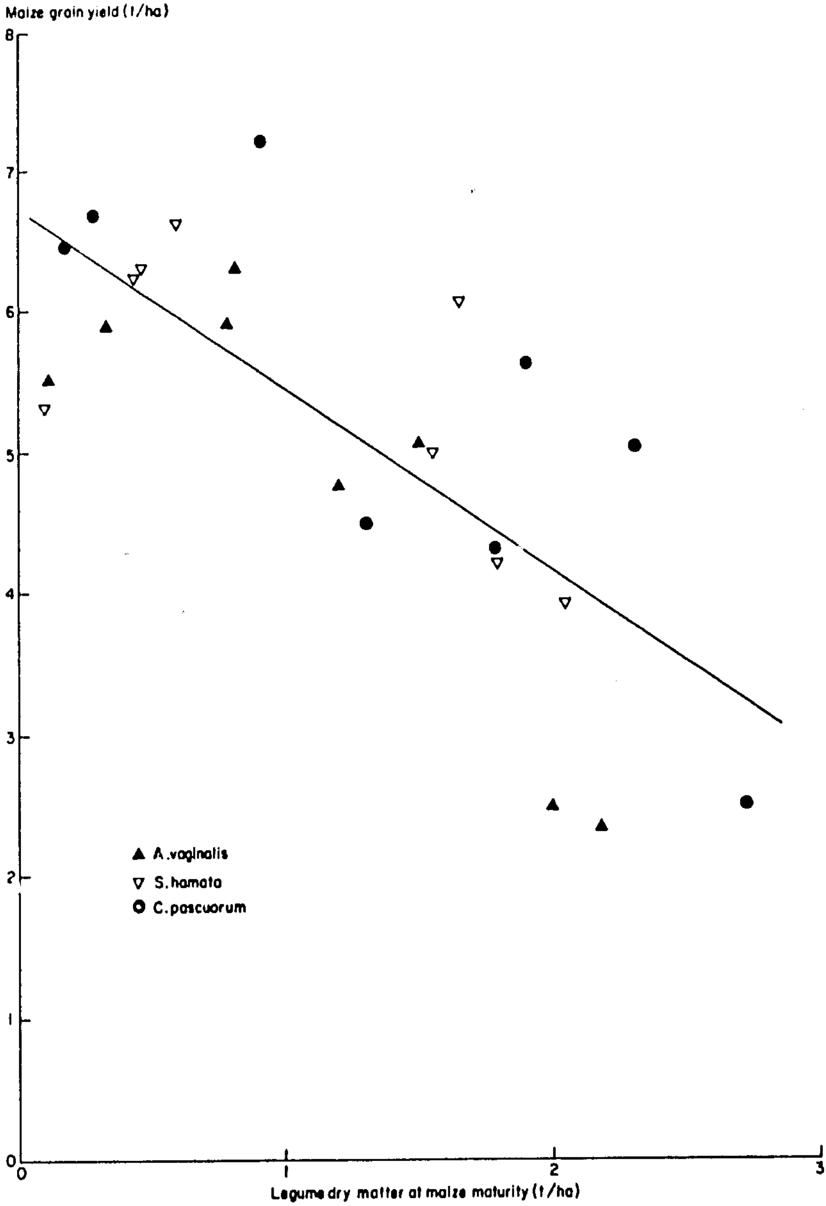
Experiment 3 was carried out in the 1983/84 wet season. Maize cultivar and cultural and sampling methods were the same as in Experiment 2, but the climbing legume *C. pascuorum* was not included. Nitrogen rates were: 25 kg/N ha broadcast at sowing (N1); 50 kg N/ha broadcast at sowing (N2); 50 kg N/ha broadcast at sowing and 50 kg N broadcast 30 days after sowing (N3); 100 kg N/ha broadcast at sowing and 100 kg N/ha broadcast 30 days after sowing (N4). The fertilizer was watered into the soil by rain after the first application and by irrigation after later applications. The experiment was a split plot design with N rates as main plots and legume species as subplots. There were 4 replicates and subplot size was 14 m x 3 m. As in Experiment 2 N was applied as ammonium sulphate and irrigation maintained an adequate water supply. Fertilizer enriched with ^{15}N was applied to microplots in the N1, N2, and N3 treatments which were sampled at 30 days after sowing, at silking and at maize maturity. The rate of ^{15}N application and microplot size were the same as in Experiment 2. Yield measurements at maize maturity were from 5 m^2 for maize and 2.25 m^2 for the legumes. Chemical analyses were similar to those of Experiment 2. The proportion of photosynthetically active radiation reaching the legume understory was measured with a Licor line sensor on two occasions during maize grain filling (10 and 24 days after silking). The mean value of radiation received at five positions at the top of the legume canopy in each plot was expressed as a proportion of that above the maize crop.

RESULTS AND DISCUSSION

Under the cultural and environmental conditions of Experiment 1, maize grain yield decreased as legume production increased (Figure 1). There were no significant differences among species and the common regression through all points accounted for 56 % of the variance. The reduction in grain yield (1.28 t of grain forgone for each tonne of forage produced) is economically unacceptable.

Meteorological records for this season show that rainfall was above average and well distributed, and although soil water was not monitored, water balance simulations confirm that the water supply to the plants in this season was very favourable. CORNF (Stapper and Arkin, 1980) was used for this calculation, and the effect on water use of increased leaf area due to intercropping was approximated by increasing maize plant density and leaf area per plant in the model. Simulated available soil water was high throughout

Figure 1. *The effect of yields of intercropped legumes on grain yield of maize, Experiment I.*



the season and declined to 30 - 35 mm at maize maturity. It seems unlikely that water shortage accounted for the depression of maize yield by intercrops.

Seed yield of all legumes was low (Figure 2) but, except for *S. hamata*, was sufficient for re-establishment. Argel and Humphreys (1983) have shown flowering and inflorescence development of *S. hamata* to be sensitive to decreased irradiance.

In Experiment 2 the presence of an understory of *C. pascuorum* significantly reduced maize grain yields and N uptake at all N rates (Figures 3 and 4). This twining legume severely shaded maize during grain filling, irrespective of N supply. The commencement of climbing by this legume in relation to stage of maize development is critical in intercropping (unpublished data).

Under conditions of high N supply the presence of *S. hamata* or *A. vaginalis* had very little effect on maize yields, but there were considerable yield reductions at lower N rates. Both legumes resulted in a 10 % reduction in maize grain size (data not shown). Table 2 shows that there were also significant effects of the presence of *A. vaginalis* and *C. pascuorum* on grain number. The lack of any effect of *S. hamata* on grain number is consistent with the observation that this species produced a much smaller proportion of its yield prior to maize anthesis than did the other legumes. It is during the period between cob initiation and anthesis that potential grain number of maize is determined. Production by *A. vaginalis* would have been underestimated as senescence was advanced and leaf loss high by the time of harvest, at maize maturity.

The ^{15}N data confirm that, while recovery of fertilizer applied at the medium and low rates was low, there was competition for N between maize and the legumes (Table 3). Fertilizer recovery by the legume was highly variable and would have been underestimated due to leaf drop, particularly for *A. vaginalis*. The mean reduction in recovery of fertilizer N by maize due to intercropping was significant ($P < 0.05$), but there were no significant differences between

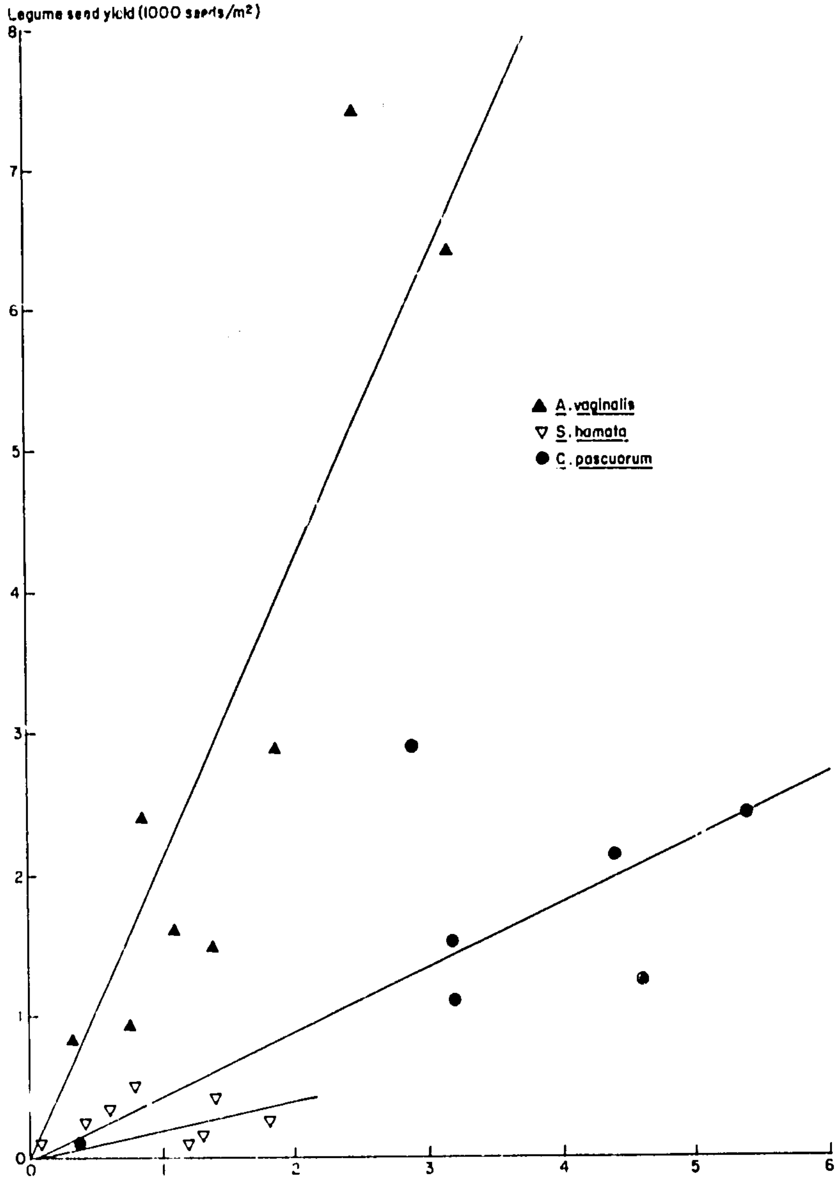


Figure 2. *The relationship between seed production and dry-matter yields of intercropped legumes, Experiment 1.*

Figure 3. *Effect of nitrogen supply on yields in intercropping systems, Experiment 2. (a) Sole maize; (b) Maize/S. hamata; (c) Maize/A. vaginalis; (d) Maize/C. pascuorum.*

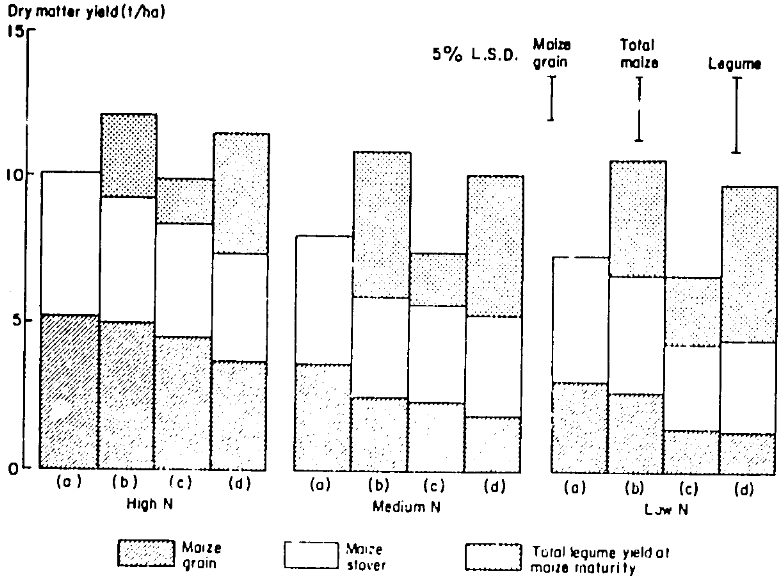


Figure 4. *Effect of nitrogen supply on nitrogen yields in intercropping systems, Experiment 2 (a, b, c and d as in Figure 3).*

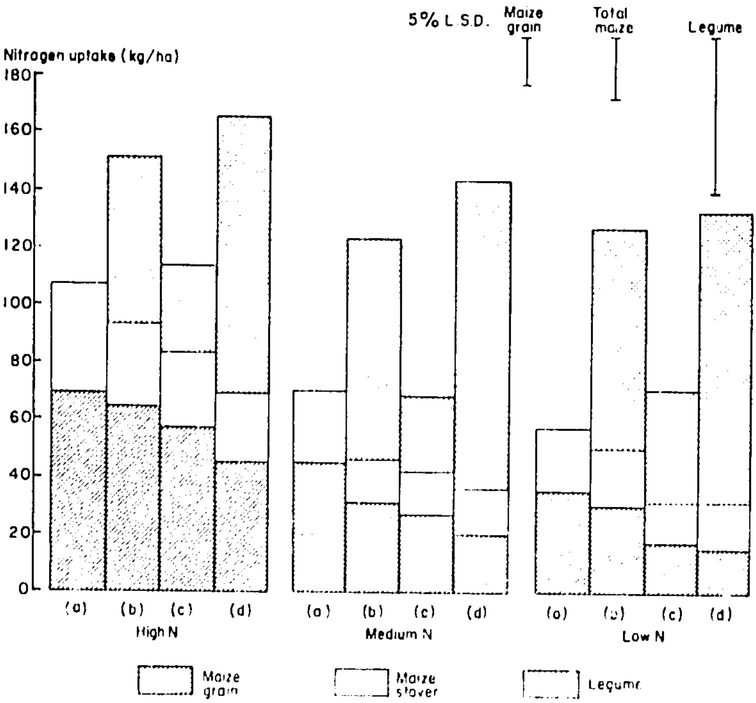


Table 2. The effect of intercrop on maize grain number, Experiment 2.

Cropping system	Grain number ($\times 10^{-7}$/ha)
Sole maize	1.84
Maize/*A. vaginalis*	1.41
Maize/*S. hamata*	1.73
Maize/*C. pascuorum*	1.20
LSD (5%)	0.26

Table 3. Average recovery of ^{15}N-labelled fertilizer nitrogen by maize and legume intercrop when applied at medium and low rates, Experiment 2.

Cropping system	Recovery %	
	Maize	Legume
Sole maize	15.8	
Maize/*A. vaginalis*	7.5	2.3
Maize/*S. hamata*	11.1	4.4
Maize/*C. pascuorum*	7.3	5.4
LSD (5%)	7.5	3.5

legumes in this effect. Nevertheless, the trends shown in Table 3 are of importance. Competition for fertilizer N tended to be least from *S. hamata*, and this legume has been shown in Figures 3 and 4 to have least effect on maize grain yield and N uptake at all fertilizer rates. There was no interaccion between legume species and N application rate.

The 1983/84 season was very wet, and the plots in Experiment 3 were frequently waterlogged. Consequently, establishment and early growth of the legumes (particularly *A. vaginalis*) were poor. Average maize grain dry weight ranged from 2.0 t/ha for treatment N1 to 7.8 t/ha for N4. Figure 5 shows the effect of each of the legumes on total yield, N uptake and ^{15}N fertilizer recovery averaged over N rates. Table 4 shows the effect on maize grain yield and components of yield. (There was no interaction between legume and N rate for any measured characteristic.) Intercropping had a consistent deleterious effect on maize performance, but any competitive effects were small. Uptake of fertilizer N was very rapid; even that applied 35 days

Figure 5. *Effect of intercropping maize with A. vaginalis and S. hamata on (a) total maize dry-matter yield, (b) maize nitrogen uptake and (c) ^{15}N-labelled fertilizer recovery by maize, Experiment 3.*

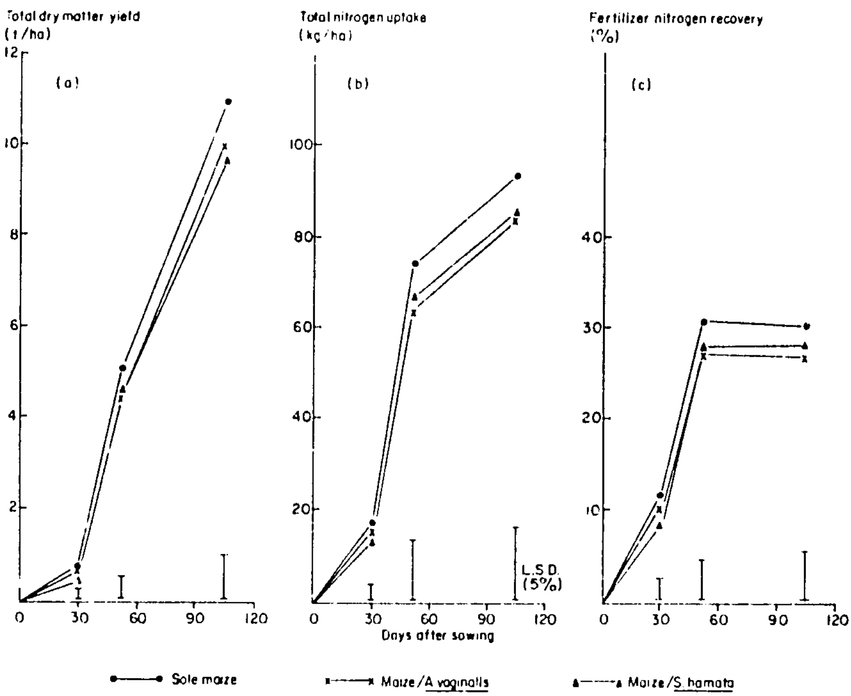


Table 4. Effect of intercropping on maize yield and components of yield averaged across nitrogen treatments, Experiment 3.

Cropping system	Grain yield (kg/ha)	Grain number /ha (x 10^{-7})	1000 grain wt (g)
Sole maize	4974	2.02	241
Maize/*A. vaginalis*	4377	1.76	243
Maize/*S. hamata*	4345	1.76	240
LSD (5%)	659	0.24	11

after sowing was taken up by the time of silking, and N uptake during grain filling was therefore from non-fertilizer soil sources. The growth and N uptake of each of the legumes at fertilizer rates where ^{15}N was applied are shown in Figure 6. As in Experiment 2, production by *S. hamata* was considerably better than that of *A. vaginalis*, but, as expected from Figure 5, fertilizer N use by these legumes was low.

In contrast to results from Experiment 1, seed production from both legumes was good (Figure 7) even though shading by the maize was severe at high rates of N application (Table 5). This experiment received supplementary irrigation so that water stress was prevented before maize maturity. The CORNF model showed approximately 70 mm of available water in the root zone at maize harvest and the improved moisture availability at this time compared with Experiment 1 might have been responsible for the better legume seed yields. There is a clear relationship between dry-matter yield and seed yield of *A. vaginalis* but less so for *S. hamata*. While the former matured at the same time as the maize, the latter would have continued to grow after maize senescence while moisture was available, and its seed yield would have been heavily dependent on dry-matter production after maize maturity.

Figure 6. *Effect of nitrogen fertilizer rate on dry-matter yield, nitrogen yield and ¹⁵N-labelled fertilizer uptake of (a) A. vaginalis and (b) S. hamata when intercropped with maize, Experiment 3.*

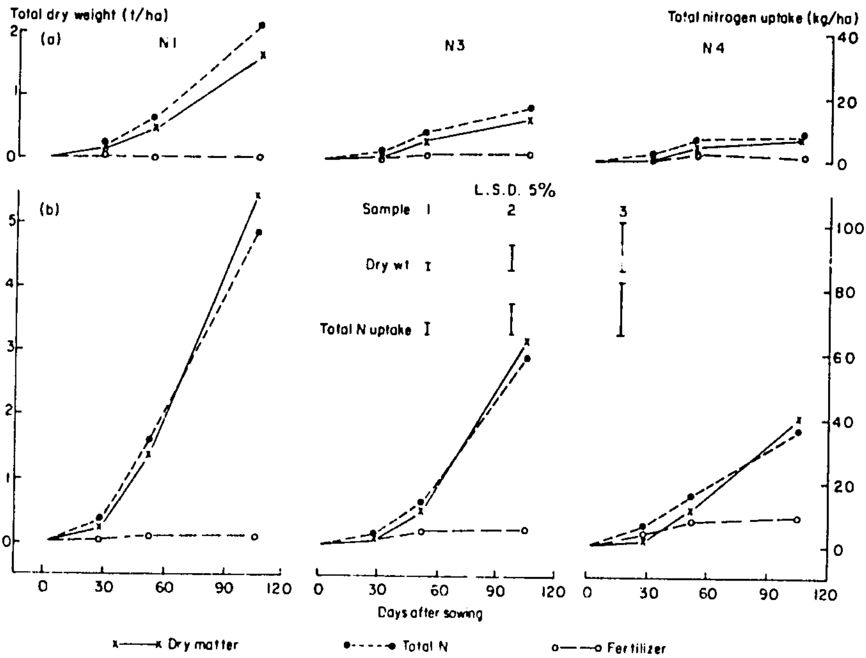
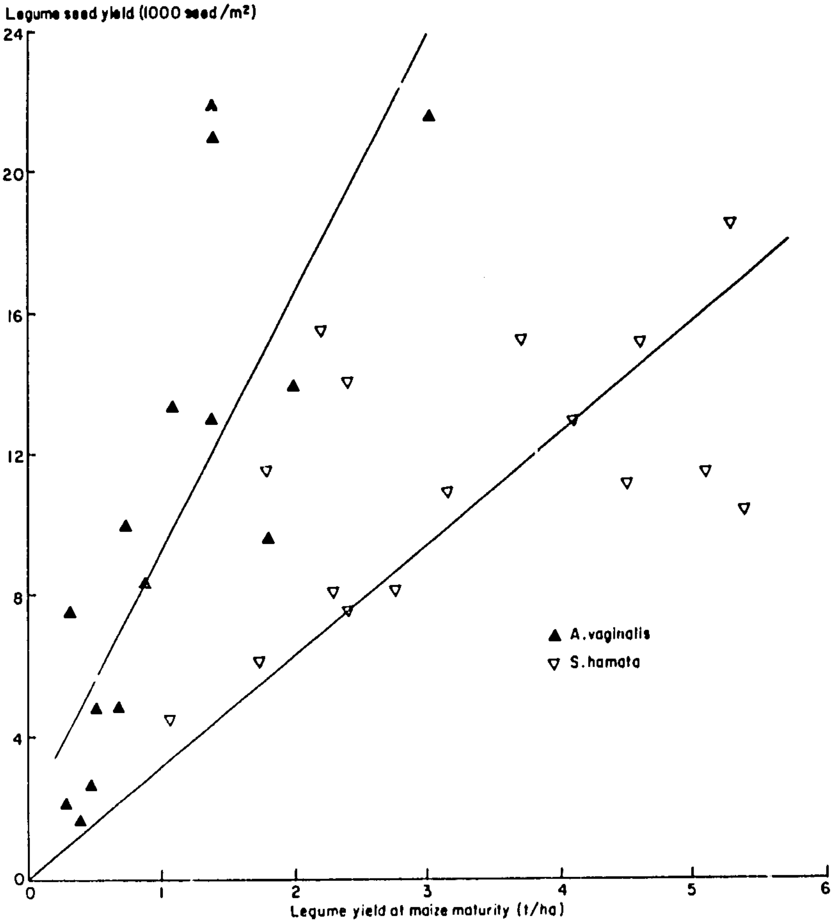


Table 5. Effect of nitrogen fertilizer rate on proportion of incident radiation transmitted to the top of the legume understory during early maize grain filling, Experiment 3.

Cropping system	Proportion of incident radiation transmitted			
	N1	N2	N3	N4
Maize/*A. vaginalis*	0.59	0.45	0.34	0.18
Maize/*S. hamata*	0.65	0.40	0.35	0.17

Figure 7. *Relationship between seed production and dry-matter yields of intercropped legumes, Experiment 3.*



For a given yield of legume N, the extent of competition for fertilizer and soil mineral N will depend on the proportion of N that the legume fixes from the atomosphere. The isotope dilution technique can be used to measure N fixation. However, Figures 5 and 6 show that there was no ^{15}N available during grain filling in Experiment 3 and therefore probably not in Experiment 2 either, and that growth and N uptake patterns of the maize and associated legumes were different. The data on legume ^{15}N uptake at earlier harvests was highly variable and complicated by poor legume establishment and poor early growth compared with that of the maize, and no attempt has been made to calculate fixation by this method (Witty, 1983). Nitrogen fixation may also be estimated by comparing N yield from a non-fixing system with that from a fixing system (the difference method). This calculation has not been done for *A. vaginalis* because of the large N loss due to leaf drop, but data are presented in Table 6 for the other legumes in Experiments 2 and 3.

Table 6. Estimates by the difference method of the percentage of nitrogen derived from fixation by *S. hamata* and *C. pascuorum* in Experiments 2 and 3.

(a) Experiment 2	Legume		(b) Experiment 3	
N rate	*S. hamata*	*C. pascuorum*	N rate	*S. hamata*
Low	91	74	N1	87
Medium	69	68	N2	92
High	72	60	N3	109
			N4	40

Rennie (1984) found that the difference method underestimated fixation particularly when soil N availability was high, and that it was less precise than the isotope dilution method, so one must be careful in drawing conclusions from data of this nature. It appears however, that fixation by these forage legumes is only severely restricted by mineral N when supply of mineral N is high. Shading can also reduce N fixation in intercropping systems (Wahua and Miller 1978; Nambiar et al, 1983). Both nodule number and specific nodule activity can be affected, but the data from these experiments do not allow a distinction to be made between the direct effect of N supply on fixation and an indirect one through increased shading resulting from improved maize growth.

The small reductions in maize yield due to the presence of these forage legume intercrops in Experiment 3, compared with the large reductions in Experiments 1 and 2, cannot be easily explained in terms of legume N fixation. The timing of the onset of competition may be critical. It has often been shown (Hanway, 1962; Allison, 1984), and it is clear from Experiment 3, that maize takes up most of its N prior to grain filling, and a large proportion of grain N results from redistribution within the plant. Competition for N commencing prior to grain filling, when demand is high and potential grain yield is determined, is therefore likely to have a greater effect on maize production that competition during grain filling. As well as helping to explain differences between the effects of *A. vaginalis* and *S. hamata*, this may explain the smaller competitive effect of the legumes in a season when their establishment and early growth were poor.

CONCLUSIONS

There is no evidence from field trials carried out at Katherine, in northern Australia, that forage legumes when intercropped with maize made any contribution to the N economy of the cereal. The effect of intercropping on maize grain yield varied with environmental conditions, but was most negative under conditions favouring establishment and early growth of the legume, particularly when N supply was low. Species differences were probably related to growth pattern and phenology.

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PHOSPHORUS MANAGEMENT WITH SPECIAL REFERENCE TO FORAGE LEGUMES IN SUB-SAHARAN AFRICA

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ABSTRACT

The paper summarises available information on the P status of soils, effect of P application on nodulation, dry-matter and seed production, crude-protein and dry-matter digestibility; use of slow release sources of P; differences among species and varieties in their response to P; assessment of P status of forage legumes; P fertilization based on cropping systems and P nutrition of plants vs animals. Future lines of research that need to be undertaken on some of these aspects are also highlighted.

INTRODUCTION

Aubert and Tavernier (1972) reported that Aridisols cover approximately 36.8% of the total area in tropical Africa, Alfisols about 21.0%, Ultisols and Oxisols approximately 22.6% and Entisols 14.1%. Inceptisols and Vertisols cover 2.5 and 2.1% of the total area, respectively. Phosphorus deficiency seems to be one of the most widespread soil constraints in the majority of these soils. Field

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experiments throughout Africa have demonstrated that crops respond to moderate amounts of P fertilizer and their residues (Le Mare, 1984).

Phosphorus deficiency effects N fixation in legumes through its effect on root infection, nodule development and nodule function and plant growth. Nitrogen fixation by forage legumes in sub-Saharan Africa has been reviewed by Haque and Jutzi (1984), while this paper reviews P investigations with special reference to forage legumes in the region, as background information for future studies.

PHOSPHORUS STATUS OF SOILS

The P status has been reported in Nigeria (Bates and Baker 1960; Udo and Uzo, 1972; Uzu et al, 1975; Juo and Fox, 1977; Udo, 1977; Udo and Ogunwala, 1977; Udo and Dambo, 1979; Juo, 1981; Kang and Fox, 1981; Le Mare, 1981), Sierra Leone (Odell et al, 1974; Rhodes, 1977), Ghana (Nye and Bertheux, 1957; Oteng and Acquaye, 1971), Kenya (Hinga, 1973), Tanzania (Uriyo and Kasseba, 1973; Uriyo et al, 1977 a, b), Malawi (Maida, 1983), Swaziland (Haque, 1983) and Ethiopia (Desta Beyene, 1984; Sahlemedhin Sertsu and Ali, 1983). Phosphorus status of French speaking countries in Africa and Madagascar and West African savanna soils was reviewed by Pichot and Roche (1972) and Jones and Wild (1975) respectively.

Some of the highlights of above articles and reviews are given below:

* Soils that fix large quanti ies of P are: Oxisols, Ultisols, Andepts, oxic Alfisols and Inceptisols.

* In most soil profiles, total and available P decline with depth and available P of surface soils does not seem to be adequate for optimum crop production.

* In acid soils, most of the applied P is sorbed by various constituents and P sorption increases with

depth within the profile due to increasing sesquioxide and clay contents.

* Soil erosion is a serious problem in the region (El-Swaify and Dangler, 1982). However, if the surface soil is eroded, the P requirement for optimum plant growth on most of these soils would increase.

* Crop residue management investigations on a Nigerian soil suggest that the beneficial effect of burning is primarily the addition of P.

* Soil burning (*guie*) in some parts of the Ethiopian highlands destroys organic matter and sharply increases P availability (Mesfin Abebe, 1981).

PHOSPHORUS MANAGEMENT

Response of forage legumes to applied phosphorus

Phosphorus is the most important nutrient in the successful establishment of forage legumes, as indicated in Table 1. The effect of soil type and P supply on dry-matter production of three African clovers is shown in Figure 1. The main conclusions of Haque and Jutzi's (1984) review of African data are outlined below.

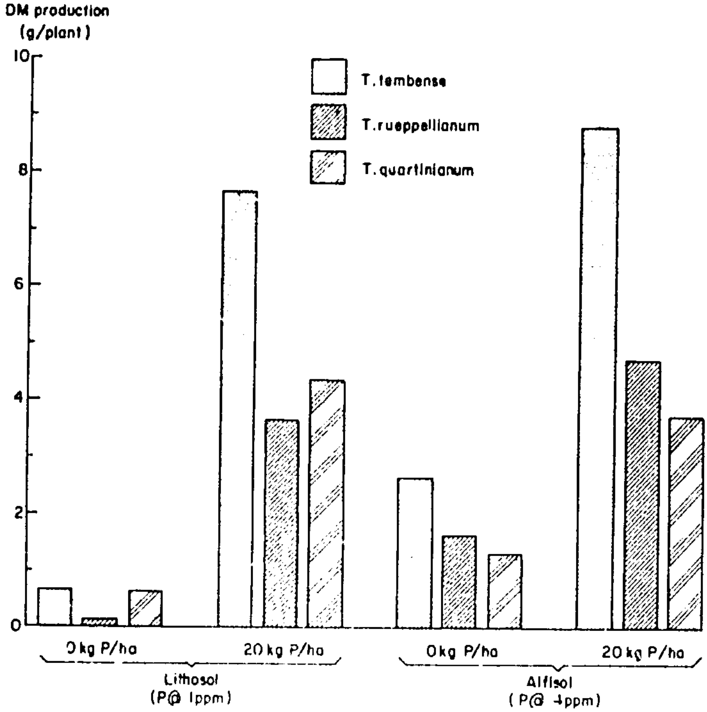
In addition to its effects on dry-matter yields of legumes, P often increases nodulation and hence increases N or crude-protein content, P concentration or uptake by the plant. Phosphorus application may also increase the digestibility of dry matter. Two recent examples of these types of responses reported by Jutzi and Haque (1984) and by Mohamed-Saleem and von Kaufmann (1985) are shown in Table 2 and Figures 2, 3 and 4.

Table 1. Legume yield responses (dry matter/seed) to phosphate application under field conditions.

Country	Species	P (kg/ha)	Response (%)	Reference
Ethiopia	Native Trifolia (22)	41	16-948	Kahurananga and Tsehay Asres (1984)
	Native Trifolia (6)	35	155-760	Akundabweni (1984)
	Native Trifolia (3)	30	479	Jutzi and Haque (1984)
	T. steudneri (TSP)	45	723	Haque and Jutzi
	T. steudneri (PR)	45	704	(1985)
Kenya	*T. subterraneum*	24	19	Bampus (1957)
	T. semipilosum	-	+	Strange (1961)
	Desmodium uncinatum			
	D. intortum	-	100	Kenya et al
	T. semipilosum			(1971)
Nigeria	*Leucaena leucocephala*	80	-	Sanginga et al (1984)
	S. guianensis	25	45	Haggar (1971)
	S. guianensis cv Cook	35.2	95	Mohamed-Saleem and von Kaufmann (1985)
	S. hamata cv Schofield	35.2	140	
	S. hamata cv Verano	35.2	106	
	Stylosanthes spp.	9-26	+	Agishi and Asare (1980)
Uganda	*S. guianensis*			
	T. subterraneum	-	+	Horrell and Court (1965)
	T. repens	67	+	Morrison (1966)
	T. semipilosum	26	35	Suttie (1970)
	S. gracilis	67	19	Wendt (1970)
	D. intortum	20	82	Wendt (1971)
	Medicago sativa	197	81	Olsen and Moe (1977)
	S. gracilis		10	
Zimbabwe	*Stylosanthes* sp.	10	+	Clatworthy (1984)

Source: Haque and Jutzi (1984)

Figure 1. *The effect of soil type and P supply on dry-matter production of three African clovers in the greenhouse, 1984.*



Source: ILCA (1984)

Use of slow-release phosphorus sources

In acid soils that fix large quantities of P, applying phosphate rock (PR) is often more effective and economical than applying superphosphate. Phosphate rocks are reactive in acid soils and costs per unit of P may be as low as one-third to one-fifth those of superphosphate. The effectiveness of PR depends on its solubility, fineness, time of reaction and the soil pH (Sanchez and Uehara, 1980).

Figure 4 shows the dramatic effects of both triple superphosphate (TSP) and EPR on *Trifoilium steudneri* grown on a P-deficient Vertisol. The clover grew very poorly when no P was applied and reacted similarly to both TSP and EPR at 15, 30 and 45 kg P/ha. Triple superphosphate was more effective than EPR only at 60 kg P/ha.

Table 2. Growth characteristics of three African clovers (*Trifolium tembense, T. rueppellianum* and *T. steudneri* 6 and 12 weeks after planting, as influenced by N/P fertilizers.

	Weeks after planting	Control	DAP		TSP		LSD
		0/0	9/10	27/30	0/0	0/30	0.05
Plant weight(g)	6	0.78	2.37	3.67	1.57	2.38	0.93
	12	1.43	4.32	8.05	3.85	8.28	2.34
Nodules/ plant	6	4.07	12.00	15.46	9.23	11.32	2.96
	12	12.24	18.81	27.44	20.36	29.19	6.71
Nodule weight (mg)	6	27	139	139	99	175	22
	12	31	77	180	69	124	31
% P	6	0.20	0.26	0.39	0.29	0.34	0.04

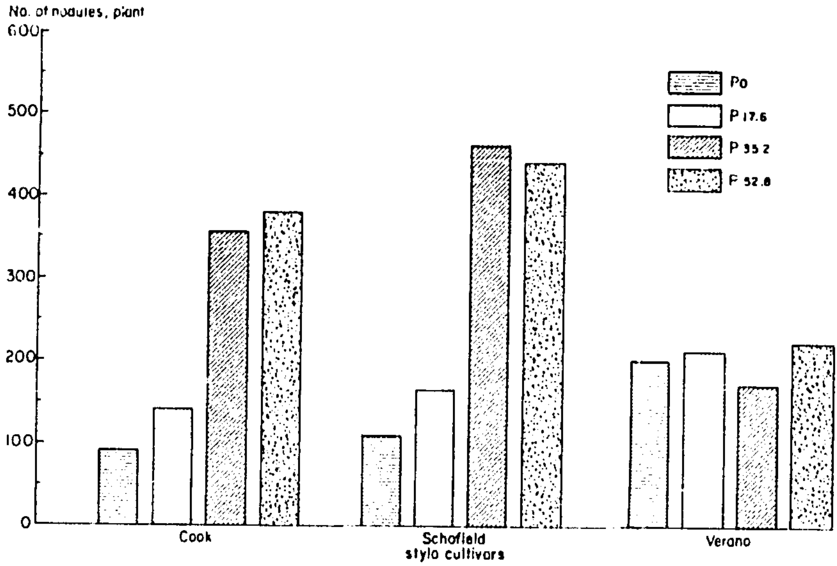
N and P levels (kg N and P/ha)

Source: Jutzi and Haque (1984).

Applying 15 kg P/ha as EPR increased dry-matter yield more than six-fold compared with the unfertilized control. Residual effect of TSP and EPR significantly increased dry-matter yield of *T. quartinianum* as compared with the control. Applying 15 kg P/ha as EPR increased dry-matter yield 3.5-fold over the control (Figure 4).

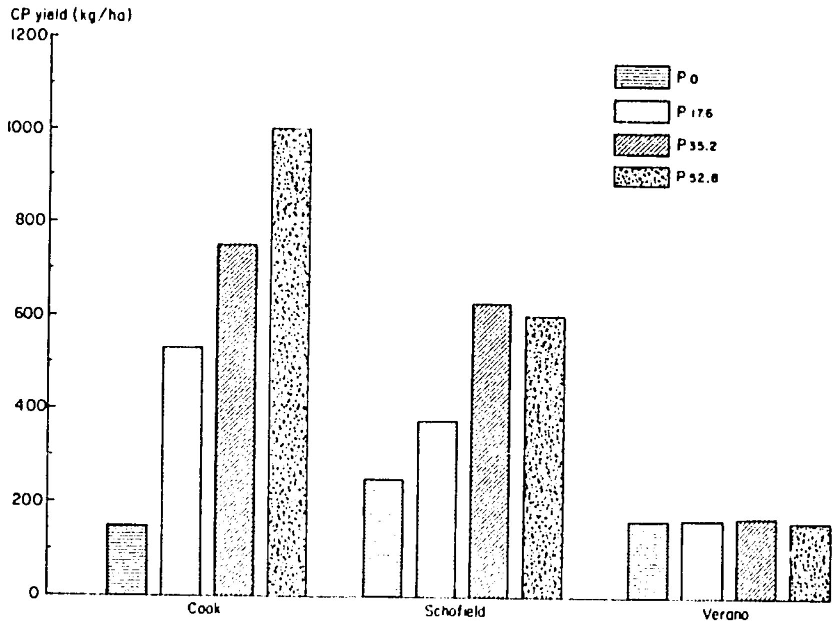
Many African phosphate rocks are low in chemical reactivity and are unsuitable for direct application on short-season crops (IFDC, 1984). An alternative may be to broadcast the PR and band a soluble source to provide P while the PR dissolves. This technique has been successful in

Figure 2. *Effect of phosphorus on nodulation of three stylo cultivars.*



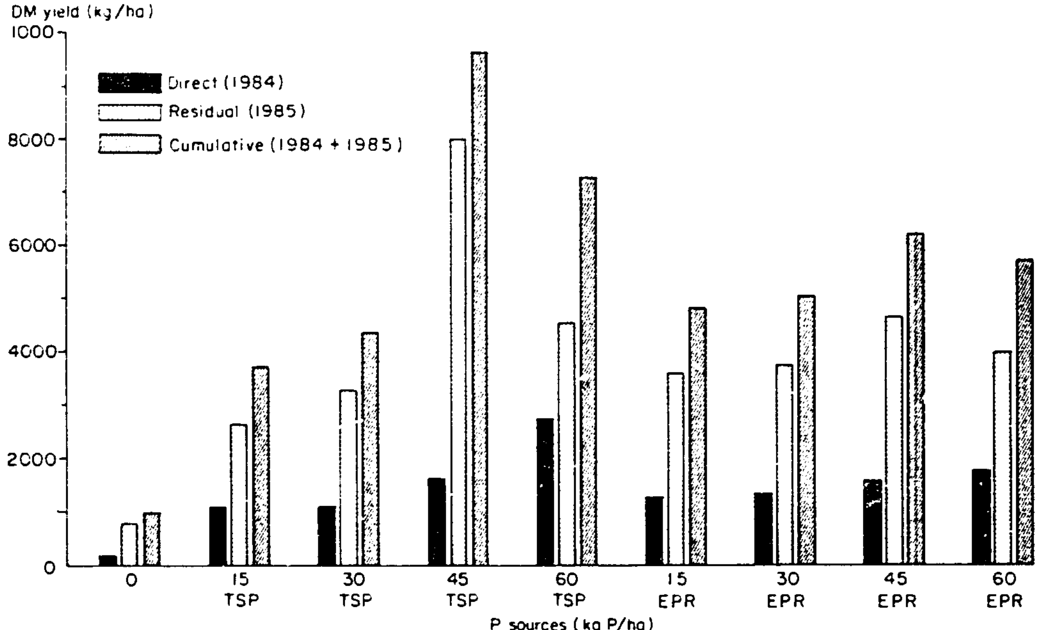
Source: Mohamed Saleem and von Kaufmann (1985)

Figure 3. *Effect of phosphorus on crude protein production of three stylo cultivars.*



Source: Mohamed Saleem and von Kaufmann (1985)

Figure 4. *Direct, residual and cumulative effects of TSP and EPR on dry matter production of clovers on a Vertisol at Shola.*



Source: Haque (1986a).

Africa with locally available PR of low citrate solubility (Pichot and Roche, 1972).

The effect of mixtures of TSP and EPR was studied on a Vertisol at Shola using *T. quartinianum*. All mixtures significantly increased dry-matter yield. A 1:1 mixture of TSP and EPR gave a five-fold increase in dry-matter production of the clover although the highest dry-matter yield was obtained with TSP at 60 kg P/ha. Other mixtures of TSP and EPR gave smaller yield increases, possibly due to the late planting of the experiment (Haque, 1986b).

IFDC phosphate research continues to support the view that acidulated PR is a viable P fertilizer alternative for sub-Saharan Africa (IFDC, 1983).

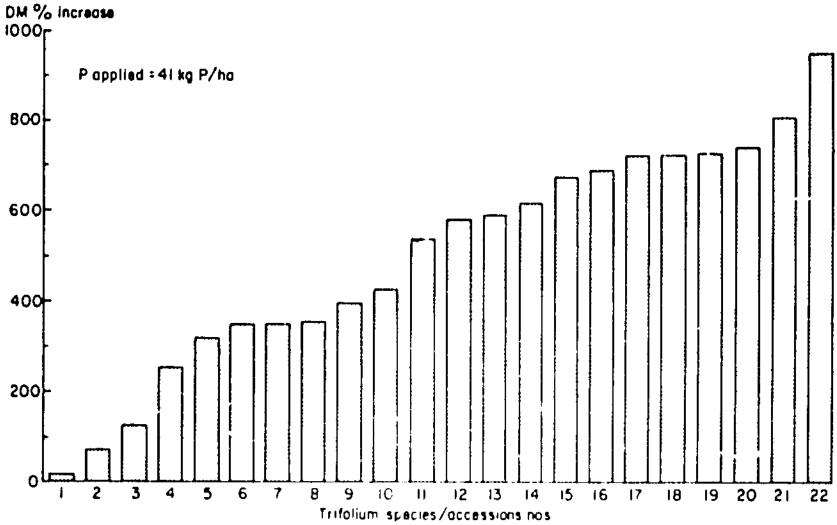
Species and varietal variation in response to phosphorus

Adapting plants to the soil's limitations rather than the traditional approach of adapting the soil to meet crop requirements is an essential research option for smallholder contexts. Large differences in the response of clover species and varieties to P are displayed in Figure 5. The use of varieties more tolerant to low levels of available P will result in more efficient use of fertilizer P. Clovers tolerant to low P are likely to have lower P concentration in their tissues. Their nutritive value may thus be lower than other cultivars/species. Direct P supplementation to cattle in the form of salts to offset deficiency may be needed.

Assessing phosphorus status in forage legumes

Soil testing: Several methods for determing available soil P have been developed to provide a basis for fertilizer recomendations. Among the methods, Bray, Truog, Morgan, Olsen and Saunder and their modifications have been widely used and their suitability has been reported in West Africa (Halm, 1965; Oteng and Acquaye, 1971; Agboola,1972; Haque and

Figure 5. *Percentage DM yield increase of native Trifolium species with phosphate application at Shola, 1983.*



ILCA A/C No

6261 (1)	6218 (7)	6268 (13)	6260 (19)
6290 (2)	9055 (8)	6220 (14)	5774 (20)
6277 (3)	6264 (9)	8521 (15)	8501 (21)
8528 (4)	6304 (10)	5729 (16)	5799 (22)
6209 (5)	8514 (11)	8543 (17)	
9058 (6)	6275 (12)	6263 (18)	

Source: Kahurananga and Asres Tsehay (1984)

Lahai 1977), Central Africa (Saunder, 1956; Lungu, 1965) and East Africa (Robinson and Semb, 1968; Osborne and Allan, 1972). Adepetu and Corey (1976) observed that values of P mineralised during cropping correlated better with P uptake by the crop than did values of extractable P, indicating the importance of evaluating the organic-P content of the soil.

Phosphorus sorption isotherms: The soils of sub-Saharan Africa are highly variable. Soil testing services in the region are minimal because of the cost of setting up such services and the time involved in making correlation studies of crop yields and various chemical extractants. The P sorption approach provides a basis for estimating P needs of crops for a given soil-crop combination (Beckwith, 1965; Fox and Kamprath, 1970; Memon and Fox 1983), which is not the case for most conventional methods. Phosphate sorption isotherms have found increasing use in evaluating the P status of forage legumes, and, based on this, external P requirements (the P concentration in soil solution that will give near-maximum yield, usually 95 or 90%) have been determined for some forage legumes (Table 3).

Standley and Moody (1983) obtained critical external values of 0.037. 0.048 and 0.08 ug P/ml for *Stylosanthes guianensis* cv. Schofield, *Centrosema pubescens* cv. Centro and *Desmodium intortum* cv. Greenleaf, respectively. Critical P values of 0.016 to 0.017 ug P/ml have been obtained for the native Ethiopian clovers, *Trifolium quartinianum, T. tembense* and *T. steudneri* (Nnadi and Haque, 1985). The very low P requirements of these legumes indicate that they can attain maximum yield with little P fertilization and can compete effectively with grasses for P uptake.

The methodology commonly adopted for P sorption studies is that described by Fox and Kamprath (1970). As with all extractions involving sorbed P compounds in soil, the amount of P in the supernatant is affected by soil-to-solution ratio, shaking time and the addition of microbial suppressants (Probert, 1982). All these factors affect P in

Table 3. External critical phosphorus values of some forage legumes (phosphorus sorption isotherms).

Species	Critical P ug P/ml	Source
Stylosanthes hamata	0.07	Probert (1982
S. scabra	0.01	"
S. scabra	0.045	"
S. scabra CPI 55818	0.03	"
S. guianensis	0.037	Standley and Moody (1983)
Centrosema pubescens	0.048	"
Desmodium intortum	0.08	"
Trifolium pratense	0.104[a]	Wright et al (1984)
Lotus corniculatus	0.141[a]	"
Lathyrus sylvestris L.	0.074[a]	"
Trifolium quartinianum	0.016	Nnadi and Haque (1985)
T. tembense	0.017	"
T. steudneri	0.016	"

a. For 90% of maximum yield.

supernatant and consequently the critical P requirement. There is a need to standardise the methodology used in these studies.

Plant analysis and tissue testing: Plant analysis is useful for tree crops, where conventional soil tests do not measure the contribution of sub-soil and there is more time to correct the deficiencies. The concentration of an element within a plant varies with the age of the plant, plant species, cultivar and plant part. However, plant sampling needs to be standardised.

Bouma and Dowling (1982) have developed a rapid and simple leaf test for measuring P status of subterranean clover. The accuracy of this test is due to the fact that it measures the amount of inorganic P present in plant tissue. This inorganic material - found in the cell vacuoles, with some in a 'free' state between reactions - is distinct from the organic form that is tied to organic compounds such as lipids and nucleic acid. The test needs to verified on highland clovers and other forage legumes in the region.

Phosphorus fertilization based on cropping systems

It has been recognised that, for efficient use of nutrients, fertilizer recommendations should take into account the cropping system as a whole rather than individual crops. This is particularly important in the case of P, with which utilisation in the year of application is rather low and residual effects are considerable.

The residual effect of P and the differential capacities of plants to utilise soil and fertilizer P should be taken into account in making P recommendations for legume-based cropping systems.

PHOSPHORUS NUTRITION OF PLANTS VS ANIMALS

In most livestock grazing areas in sub-Saharan Africa, soils and plants are low in P. Phosphorus deficiency in grasses has been reported from Kenya (Orr and Holm, 1931; Howard et al, 1962), Tanzania (Naik, 1965), Uganda (Long et al, 1969), Swaziland (FAO, 1978), South Africa (du Toit et al, 1935; 1940) and many other countries of the region.

Phosphorus deficiencies of ruminants have been reported from Botswana, Ghana, Kenya, Malagasy Republic, Malawi, Nigeria, Senegal, Somalia, South Africa, Swaziland, Tanzania, Uganda, Zaire and Zimbabwe (McDowell et al, 1984).

FUTURE OUTLOOK

The review highlights P management in sub-Saharan Africa with reference to forage legumes. However, it is obvious that little research has been done on P nutrition of forage legumes and further research in the following areas is necessary to exploit their potential.

* Characterisation of various soil types with respect to P and calibration of P methods using forage legumes.

* A considerable number of legumes are indigenous to sub-Saharan Africa but the effect of P on root infection, nodule development and function and BNF have not been studied systematically.

* There seems to be a lack of information on external and internal critical levels of P in forage legumes in the region and there is a need for studying the P requirements of legume-based cropping systems.

* Studies on slow-release sources of P need to be intensified on legume-based cropping systems on various soil types.

* The contribution of P through plant and animal residues and a balance sheet of P in soil/plant systems need to be prepared for various ecosystems.

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PHOSPHATE-INDUCED ZINC DEFICIENCY IN STYLOSANTHES GUIANENSIS (OXLEY FINE-STEM STYLO) IN ZIMBABWE

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ABSTRACT

Trials were conducted for 6 years at two granite sand sites in Zimbabwe to study to responses of Siratro (*Macroptilium atropurpureum)* and Oxley fine-stem stylo (*Stylosanthes guianensis)* to single superphosphate applied at levels of 0 to 2400 kg/ha, applied either split (annual and biennial) or all in the first year of the trials.

Siratro yields were increased by P applications throughout the trial. Applying P initially increased stylo yields, but in the third season negative responses occurred at high levels of P application, and this progressively affected all P treatments at all sites. By the fifth season only sections of one replicate at Marondera that received extra Zn in the fourth year responded positively to P application.

There were significant correlations between Zn content of the herbage, level of P application and yield decreases from the second to the fourth season at one site. Application of Zn in the fourth season apparently prevented yield declines in plots not previously affected, and other plots adversely affected by high initial P application recovered in the sixth season, probably due to the release of immobilised Zn by weathering.

The decline in stylo yield was probably linked with Zn immobilisation in a Zn/P interaction ratio which has been referred to by a number of authors.

MEASUREMENT PROBLEMS ASSOCIATED WITH SOIL WATER STUDIES USING NUCLEAR TECHNIQUES

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ABSTRACT

Field spatial variability in association with soil water status in the root zone and different error components influencing soil water content measurements with the neutron-scattering method were evaluated under three cropping conditions. The work was carried out along three 96-m-long transects with 63, equally spaced, water content measuring sites in each. The first transect was bare soil, the second planted to ryegrass and the third planted to alfalfa. Auto-correlation and cross-correlation analysis of geostatistics were used to evaluate spatial dependence of soil water content measurements made with the neutron-scattering method. It was found that field variability in soil water content measurements was space dependent over a distance of about 56m and this implied that the measurement domain of neutron-scattering method for this particular field was an area of about 12 m diameter. Different cropping conditions did not influence the space dependence of the measurements. The results are discussed in the context of the influence of spatial dependence on field experiment designs.

Time invariance of spatial distribution of water content measurements were also discussed. It was found that some measuring sites common to all the three transects had consistently known deviations from the mean value of the measurements. This finding demonstrated that one could characterise soil water status of a given field at a

specified precision based on measurements made at a small number of locations specific for a given field but not influenced by different cropping conditions.

Total error of water content measurements with the neutron-scattering method was lowest (0.028 cm^3 H_2O/cm^3) in the bare soil and highest (0.049 cm^3 H_2O/cm^3) in the alfalfa transect for the measurements made late in the season. Relative magnitudes of error components making up the total error were nearly the same and constant in the bare soil and ryegrass transects for a period of over 100 days of measurement records, whereas in the alfalfa transect they were time dependent. The total error in the alfalfa transect late in the season was almost double that at planting time. This showed that an additional error was introduced in water content measurements as alfalfa roots developed fully.

INTRODUCTION

Since the earlier work of Gardner and Kirkham (1952) and van Bavel (1963), the neutron-scattering method of measuring soil water content in the field has gained wide acceptance. In many circumstances the neutron-scattering method has advantages over traditional methods, e.g. gravimetric sampling, because it is rather simple, non-destructive, and results of measurements can be obtained almost instantly. However, it is an indirect method, since the probes have to be calibrated. It has been shown that the effects of soil composition and bulk density on the calibration curve of neutron probes were the most common and important problems associated with the neutron-scattering method (Marais and Smit, 1962; Rawitz, 1969; Vachaud et al, 1977). Hewlett et al (1964), Sinclair and Williams (1979) and recently Haverkamp et al (1984) have evaluated various error components involved in soil-water studies in the field using the neutron-scattering method.

Vachaud et al (1984) suggested that it was feasible to identify certain measuring sites in a given field where deviations of soil water content measurements from the field mean value were nearly constant at all times. They demonstrated that this was true under a given cropping condition. The relevance of the suggested idea was that a small number of measuring sites could be identified which would characterise the soil water status of a field, thus reducing the effort and cost of measuring needed to achieve a given degree of precision. In the present work we evaluated the suggested approach under different cropping conditions.

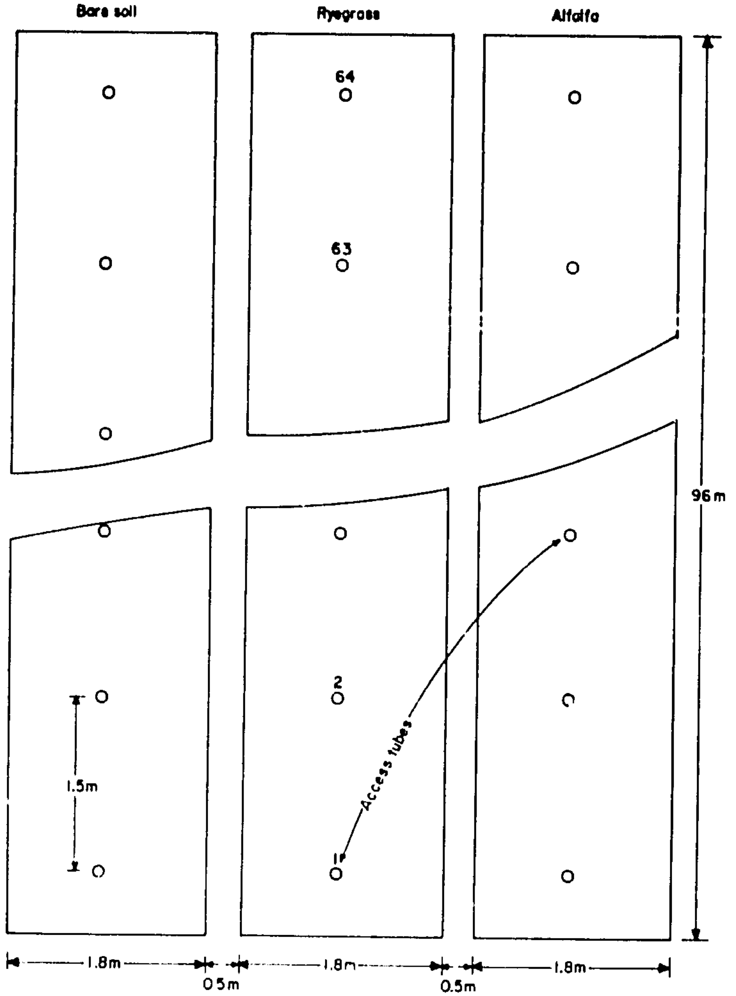
To our knowledge no work has been done dealing with measurement domains of the neutron-scattering method. Thus it was the objective of this work to examine this question in addition to analysing the errors inherent in the neutron-scattering method under different cropping conditions.

MATERIALS AND METHODS

A field experiment consisting of three transects, each 96 m long and 1.8 m wide, was set up at the FAO/IAEA Agricultural Biotechnology Laboratory research fields, Seibersdorf Laboratory, Austria, in 1984 (Figure 1). The first transect was bare soil, the second planted to rye grass (*Lolium multiflorum* L.) and the third to alfalfa (*Medicago sativa* L.). The soil was classified as a Typic Eutrocrepts with coarse clay loam texture (Fried et al, 1984). The primary objective of the experiment was to examine the influence of spatial variability in the soil water status of the root zone on nitrogen fixation of alfalfa. However the discussion here is confined to problems of measuring the soil water status in the root zone.

Neutron-probe access tubes were installed in all three transects at intervals of 1.5 m. The soil water content of the root zone was measured at 25 cm depth at all measuring sites at 2-week intervals during the summer 1984, using a Troxler 3220 Series depth neutron probe.

Figure 1. *Experimental layout in the field.*



Spatial variability

Auto-correlation and cross-correlation analysis of regionalised variable theory of geostatistics (Davis, 1973; Journel and Huijbregts, 1978) were used to assess the spatial variance structure of the measurements of the soil water status of the root zone and to evaluate possible interaction of soil water status with fertilizer uptake by the plants.

The equation for calculating auto-correlation is usually given in the form of:

$$r(h) = C(h) . C(0)^{-1} \quad (1)$$

where C(h) is the estimated autocovariance of measured values separated by vectoral distance h which is called "lag", and C(0) is the estimated total sample variance. For the one-dimensional case, the autocovariance is given by:

$$C(h) = \frac{1}{n-h-1} \sum_{i=1}^{n-h} [f(X_i) - \bar{f}] [f(X_i + h) - \bar{f}] \quad (2)$$

where f is the sample mean, n is the total number of measuring sites, and $f(X_i)$ and $f(X_i+h)$ are measured values along the experimental transect at sampling sites X_i and X_i+h. The random function describing measured data [i.e. f(X)] must show a form of stationarity for autocorrelation analysis to be valid (Davis, 1973). In the case of non-stationary data, a detrending procedure described by Bresler et al (1974) was used to meet the assumption of stationarity.

The concept of zone of influence (ZI) described by Gajem et al (1981) and Russo and Bresler et al (1981) was used to estimate the spatial measurement domain of the neutron-scattering method for measurements of the soil water status of the root zone. ZI is defined as being the distance over which the measurements in question are spatially correlated and are thus not independent.

The ZI of measurements were calculated using the statistic (Davis, 1973):

$$Z = | r(h) | \sqrt{n-h} \quad (3)$$

where Z is tabulated two-tailed deviations. For 95% confidence Z= 1.645. From equation (3) one derives:

$$r_{0.05} = \frac{1.645}{n-h} \tag{4}$$

where $r_{0.05}$ is the minimum correlation coefficient which is to be compared with experimentally measured values to calculate ZI. Thus the distance corresponding to maximum lag satisfying

$$r(h) > r_{0.05} \tag{5}$$

is defined as ZI with 95% confidence.

Cross-correlation analysis can be best used to investigate relationships among different soil properties, as well as the influence of soil properties on plant growth characteristics, such as yield, fertilizer uptake, atmospheric nitrogen fixation etc. If one designates two different sets of data as $f(X_i)$ and $g(X_i)$, both measured along the same transect sequentially, then cross-correlation of these two sets of data is given by (Davis, 1973):

$$r(h) = \frac{(n-h)\sum^{n-h} f(X_i + h)g(X_i) - \sum^{n-h} f(X_i + h) \sum^{n-h} g(X_i)}{((n-h)\sum^{n-h} f(X_i + h)^2 - [\sum^{n-h} f(X_i)]^2).((n-h)\sum^{n-h} g(X_i + h)^2 - [\sum^{n-h} g(X_i)]^2)} \tag{6}$$

Time invariance

The procedure described by Vachaud et al (1984) was followed in order to evaluate time invariability of spatial distribution of water content measurements. Deviations of any given individual measurement of soil water content, $\theta_{i,j}$ at site i (i = 1 to 64) and time j (j = 1 to 8) is calculated using the equation:

$$\Delta_{i,j} = \theta_{i,j} - \bar{\theta}_j \qquad (7)$$

where

$$\bar{\theta}_j = \frac{1}{8} \sum_{i=1}^{64} \theta_{i,j} \qquad (8)$$

In order to obtain dimensionless numbers, deviations are normalised with the equation:

$$\delta_{i,j} = \frac{\Delta_{ij}}{\theta_{ij}} \qquad (9)$$

Thus, for any location i the time average of $\bar{\delta}_i$ and standard deviation could be easily calculated. The results are discussed to evaluate the influence of different cropping conditions on time invariability of spatial distribution of root zone soil water content measurements.

Error analysis

If one wants to estimate mean water content with the neutron-scattering method in a given field where n measuring sites are chosen at random, it is of interest to evaluate the relative contribution of various errors to total covariance of estimated water content. Neutron count rates are recorded (C, counts per second) at each measuring site for a period of T seconds to measure soil water content with the neutron method. The mean count rate C_s in a standard medium is also measured for a period of T_s seconds at about same time as field measurements are made. Using a previously determined calibration curve of neutron-scattering method of the form:

$$\hat{\theta} = a + b\bar{R} \qquad (10)$$

one can easily estimate field mean water content $\hat{\bar{\theta}}$ (cm^3/cm^3). In the above relation, a and b are constants associated with the linear calibration curve, R is the field mean count rate ratio defined as:

$$\bar{R} = \frac{\bar{C}}{C_s} \tag{11}$$

where $\bar{C}$ is the field mean count rate. Assuming a and $\bar{R}$ to be independent and replacing population values by their associated astimates, Sinclair and Williams (1979) and Vauclin et al (1984) have shown that total variance of estimated field mean water content is:

$$S^2(\bar{\theta}) = [b^2 - S^2(b)]\, S^2(\bar{R}) + [b^2 - S^2(b)] \left[\frac{\bar{R}}{pT} + \frac{\bar{R}^2}{qT_s}\right] \frac{1}{n\bar{C}_s} + S^2(a) + \bar{R}^2 S^2(b) + 2\bar{R}S(a,b) \tag{12}$$

where notation S^2 is used for the unbiased estimate of variance and S is used for the unbiased estimate of covariance as used by Sinclair and Williams (1979). In the relation, p and q are the number of replicate count rates at the measuring site in the field and in the standard medium, respectively. First and second terms on the right-hand side of the relation are locational and instrumentation errors, respectively, and the remaining terms represent calibrational errors. In the present work, measurements of soil water content made with neutron-scattering method under different cropping conditions are discussed within the context of the error analysis outlined above.

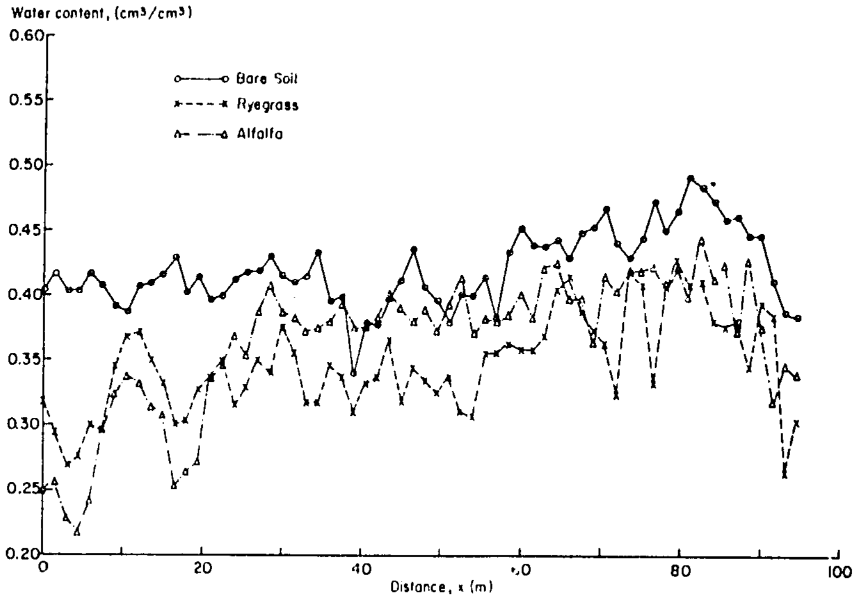
RESULTS AND DISCUSSION

Spatial variability

An example of the soil water status of the root zone measured along the experimental transects just before an irrigation is given in Figure 2. Mean soil water contents for each transect are different, with the highest value observed in the bare soil transect and the lowest in the alfalfa transect. The differences in mean values are in accord with different evaporation conditions and plant water usage in the transects. This demonstrates the value of the neutron-scattering method in studies of plant water consumption as an alternative to using lysimeters. Barrada (1965) pointed out that the main problems in plant water consumption studies lie in estimation of percolation of water below the rooting depth. However, this problem can be overcome with combined use of tensiometers and neutron gauges (De Boodt et al, 1967).

Table 1 gives a summary of basic statistics in relation to soil water content of the root zone for all the measurements. The coefficient of variation (CV) of the measurements ranged from 6.8 to 14.9%, indicating rather high variability in soil water content of the root zone of the three transects. Some portion of the observed variability in water content measurements stems from non-uniform distribution of irrigation water, in spite of the care taken to ensure uniform distribution. Because water content measurements were made every 2 weeks, irrespective of irrigation schedules, a major contribution to variability in water content measurements comes from heterogeneity of the soil itself. However, autocorrelograms of water contents constructed to cover a period of about 100 days show similar variance structure and do not seem to depend on different cropping conditions (Figure 3). Soil water content measurements with the neutron-scattering method were correlated over a distance of about 6 m (i.e. ZI = 4 lags) at the 95% confidence level indicated by the shaded area in Figure 3. This implies that the spatial measurement domain

Figure 2. *An example of spatial field variability in soil water content measured at 25 cm soil depth along the experimental transect.*



of the neutron-scattering method in the field is about 12 m. If one is to draw a field map describing soil water status, the maximum mapping unit is determined by the measurement domains of the method in question. Depending on the particular method of measurement, measurement domains may differ.

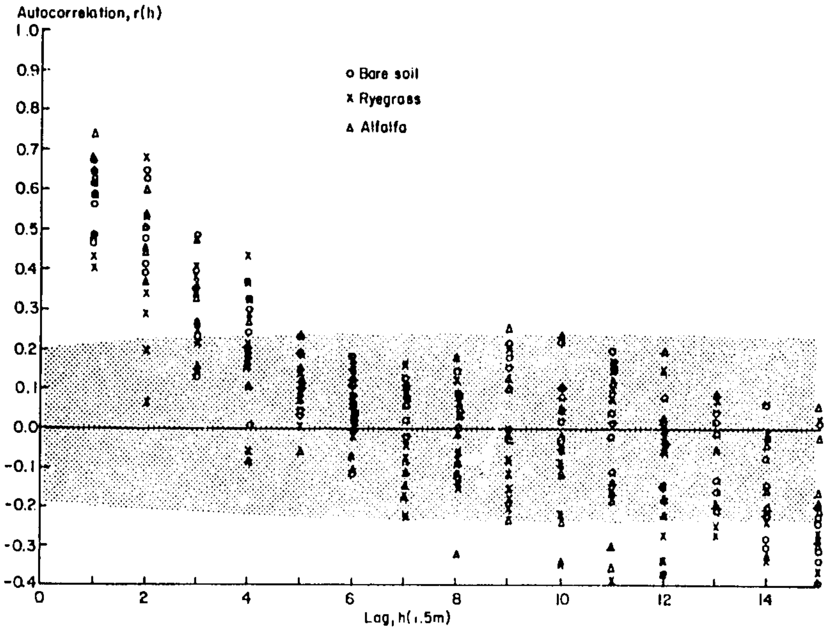
One of the important implications of spatial dependence is on field experiment designs (McBratney, 1985). As water content measurements are spatially dependent and correlated over a distance of about 6 m, treatment plots and replicates of an experiment dealing with soil water status must be separated by distances at least equal to ZI. Only under this condition can measurements made in each experimental plot be assumed to be independent, a crucial prerequisite in field experiment designs (Schmitt, 1969).

Table 1. Basic statistics of soil water content measurement (% cm^3/cm^3) in the experiment transects.

Date	1 June	20 June	10 July	26 July	10 Aug	24 Aug	10 Sept
				Bare soil			
Mean	41.1	38.0	39.3	38.4	28.4	41.6	42.1
σ^2	11.2	9.1	8.5	7.9	9.2	9.5	8.7
Min.	34.6	30.7	32.2	31.4	20.9	35.1	34.0
Max.	48.3	43.8	47.3	44.0	34.4	48.7	49.3
CV (%)	8.1	7.9	7.4	7.3	10.6	7.4	7.0
				Ryegrass			
Mean	40.3	37.3	36.3	38.4	28.5	34.9	34.8
σ^2	10.0	14.0	15.2	8.1	11.1	16.5	14.2
Min.	34.8	31.0	30.3	31.1	22.2	23.2	26.6
Max.	47.3	44.0	45.0	43.9	35.7	42.8	42.9
CV (%)	7.9	10.0	10.7	7.4	11.7	11.7	10.9
				Alfalfa			
Mean	41.9	40.2	35.3	38.4	40.7	37.8	36.5
σ^2	10.9	10.7	12.7	7.9	7.6	15.7	29.4
Min.	34.9	33.8	25.4	31.6	35.7	30.4	21.8
Max.	49.3	46.3	41.9	43.7	47.5	45.8	44.6
CV (%)	7.9	8.1	10.1	7.2	6.8	10.5	14.9

In field experiments one usually tries to avoid variability in soil conditions and sets up the experiments in those areas which appear to be relatively uniform. In as much as one can argue on the criteria used to select a uniform site for an experiment, it is possible to make use of the variability rather than avoiding it. The variability in

Figure 3. *Autocorrelations of soil water contents measured on 7 dates at 2-week intervals during the 1984 summer in the three transects.*



soil water content under the cropped transects implies that the differences in soil water content of the root zone among the measurement sites were a reflection of the variability of the soil. Thus it is possible to evaluate the influence of the soil water content in the root zone on various plant growth indicators, e.g. fertilizer uptake, nitrogen fixation, etc, simply by using inherent variability in the field without setting up special treatment plots. As an example, Figure 4 shows a strong cross-correlation between soil water content and uptake of nitrogen fertilizer by ryegrass. The nature of the possible mathematical relation describing the intercorrelation shown in Figure 4 is shown in Figure 5. Evaluation of the relation shown in Figure 5 is very difficult, if not impossible, with traditional field experiment designs where the number of treatment plots is 5 or 6 at the most. One can examine numerous other possible interrelations between soil properties and plant growth indicators with the approach described here.

Figure 4. *Crosscorrelations of seasonal mean soil water content in the root zone and nitrogen fertilizer use efficiency of ryegrass. Shaded area shows interval of random variability at 95% confidence.*

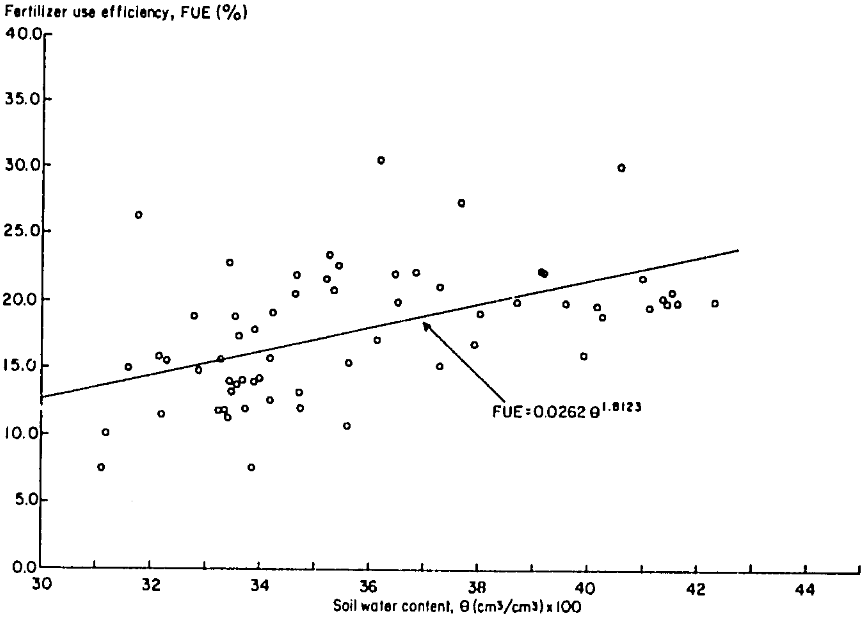
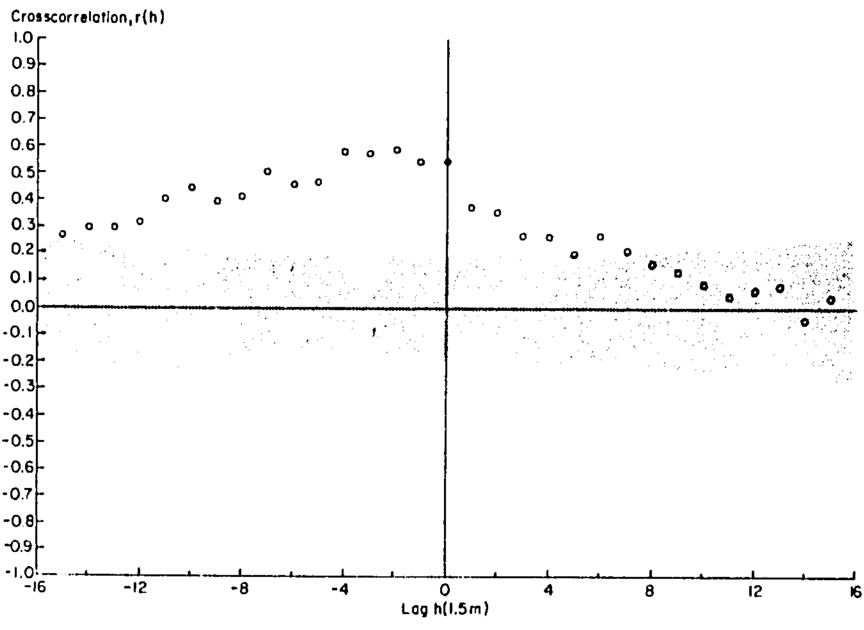


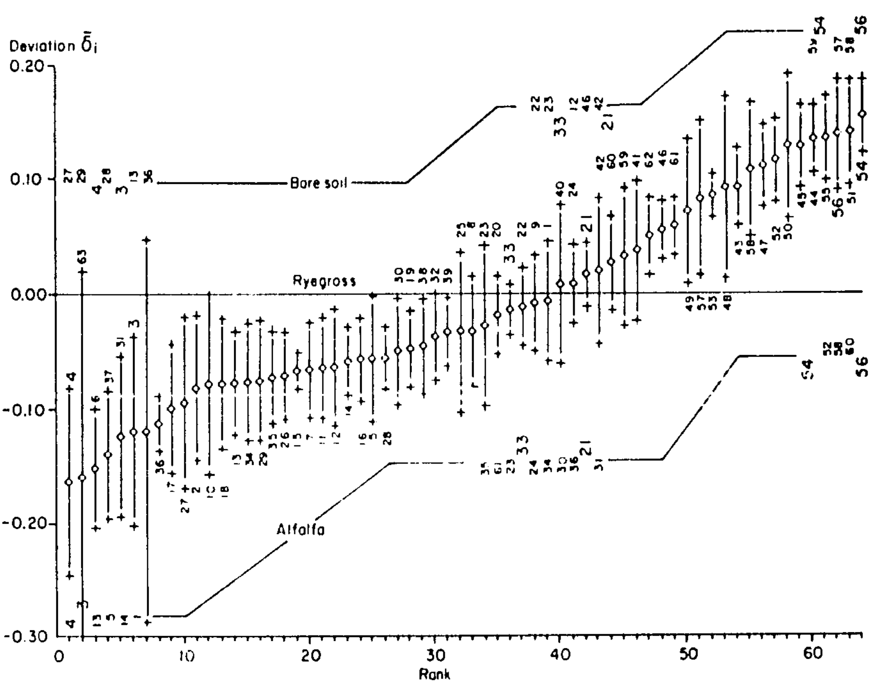
Figure 5. *Influence of soil water content in the root zone on nitrogen fertilizer use efficiency of ryegrass.*



Time invariability

Time average $\bar{\delta}_i$ and temporal standard deviation of $\delta_{i,j}$ for the three transects are calculated using equation (9) and ranked in ascending order. The results for ryegrass are shown in Figure 6. Ranks for deviations of bare soil and alfalfa for some locations are also shown on the same figure to compare with those of the ryegrass transect. It is interesting to note that some sites give values close to the average soil water content of the transect, irrespective of transect treatment. Water content measurements made at sites 21 and 53 are closest to the transect mean in the bare soil, ryegrass and alfalfa treatments. It is also possible to identify some sites that consistently either over estimate (i.e. $\bar{\delta}_i > 0$, sites 54 and 56), or underestimate (i.e. $\bar{\delta}_i < 0$, sites 3 and 4) the transect mean water content, regardless of time of measurement and different cropping conditions.

Figure 6. *Ranked relative deviations from the transect mean water content for ryegrass. Numbers refer to location of measurements and vertical bars correspond to associated standard deviations. Locations giving about same rank of deviations for bare soil and ryegrass are also shown.*



Vachaud et al (1984) explained the described behaviour in their work by a deterministic relation between soil water content and soil texture. This implies that under a given water management practice, the location with the highest clay content remains the wettest at all times. This feature may have important practical implications in irrigation management, where irrigation specialists are only interested in estimating the mean water content of the field as a whole. In this case it is possible to estimate the mean field water content based on a limited number of measurements made in a particular, previously identified, site. It would seem that a lot of effort has to be made to identify the sites which have the least deviation (i.e., $\bar{\delta}_i$) from the field mean. The authors, however, feel that the experimental fields must be characterised in any case for better field experiment designs. The approach described here can be used from the point of view of soil water studies.

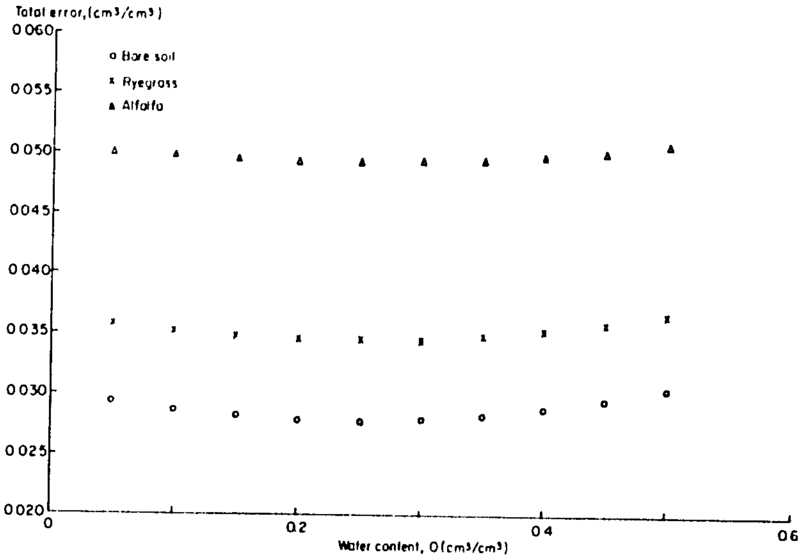
Error analysis

Parameters of the calibration curve for the neutron probe used in the experiment are given in Table 2. Total variance of soil water content measurements is calculated using these parameters in equation 12. Total errors of the measurements which are simply the square root of variances (i.e. standard deviation) exhibit a minimum when they are plotted as a function of water content (Figure 7). The mentioned behaviour varies according to cropping conditions. The lowest value of the minimum error occurred in the bare soil transect, was higher in the cropped transects and was highest in the alfalfa transect (Figure 7). As can be seen in Figure 8, relative differences with respect to magnitude of errors of the different transects were found to be time dependent. Total errors in the bare soil and ryegrass transects were nearly constant, whereas in the alfalfa transect it almost doubled as compared to errors of measurements made near to planting time. This shows that an additional error is introduced into soil water content

Table 2. Parameters of calibration curve for the neutron probe.

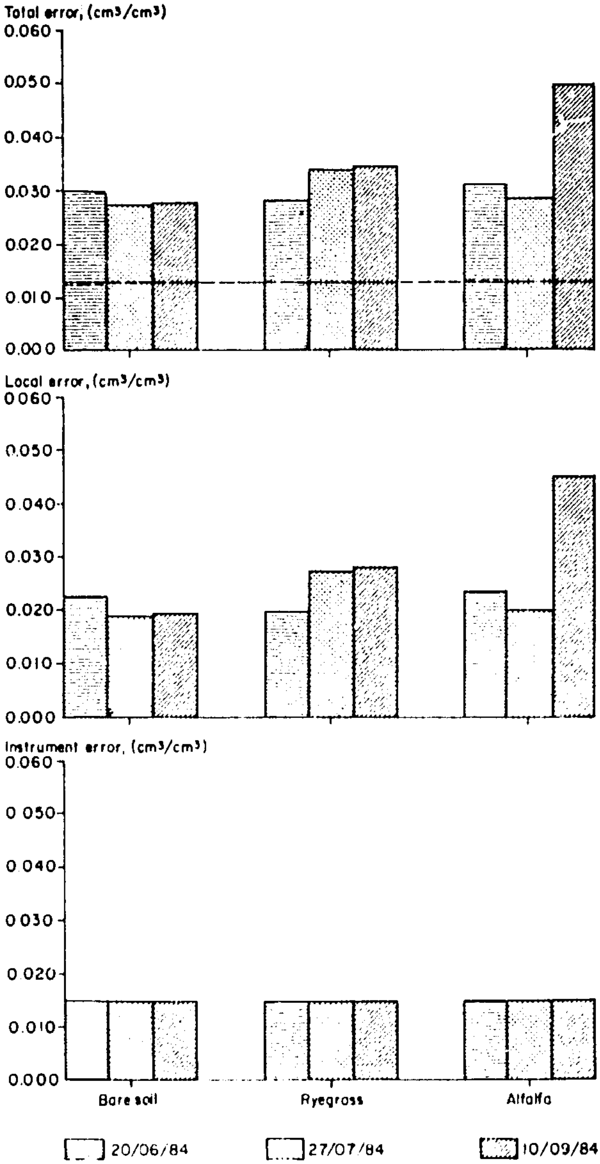
Soil depth (cm)	a	b	$S^2(a)$	$S^2(b)$	$S(a,b)$	r
25	-1.096	1.946	4.296×10^{-3}	8.705×10^{-3}	-5.990×10^{-3}	0.949

Figure 7 *Influence of field mean water content on total errors of water content measurements under different cropping conditions*



measurements as alfalfa roots develop fully. The effect was less in the ryegrass transect because the effective roots of ryegrass are confined to shallower soil depths. The discussed error reflects itself in the local error component and thus the contribution of calibration error gradually decreases at the late season (Figure 8). In conclusion it can be stated that changes of plant root density and root

Figure 8. *Time dependence of error components of soil water content measurements made with the neutron-scattering method under different cropping conditions, 1984.*



activity during the growing season can also influence calibration curves of neutron probes, in addition to soil composition and soil bulk density. The relative importance of various error components in soil water content measurements have to be evaluated under different cropping conditions as well as different irrigation management practices, and compared with other methods, e.g. gravimetric sampling, tensiometers, resistance blocks etc, to select the appropriate methodology to meet the needs of each user.

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SOME RESPONSES OF COWPEA TO DROUGHT STRESS

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ABSTRACT

Traditionally, cowpea (*Vigna unguiculata*) has been used mainly as a grain crop in the semi-arid areas of sub-Saharan Africa. However, it could be grown as a forage crop or a dual-purpose crop that provides high protein grain for human consumption and crop residues of high nutritive value for animal feed. Drought is a constraint to crop production in the semi-arid regions, the principal area of cultivation of cowpea. The effect of drought stress on plant water status, leaf area and seed yield were examined in a number of experiments. Predawn leaf water potential (PLWP) remained fairly constant (at the vegetative stage) or declined gradually (at the flowering or pod-filling stage) as duration of stress was prolonged. The difference between PLWP of stressed and unstressed plants was small, although PLWP was always lower in stressed plants. Midday leaf water potentials were much lower in the drought-stressed plants than in the unstressed plants and the differences increased as duration of stress was extended. When plants were drought-stressed at the vegetative stage, the production of new leaves and expansion of leaves ceased. Leaf area therefore remained constant. Upon termination of stress at the vegetative stage, leaf growth resumed. At maturity, leaf area and seed yield of stressed plants were not significantly different from unstressed plants. Although leaf production and expansion ceased when plants were stressed at the flowering or pod-filling stage, leaf abscission was more important in determining total leaf area per plant. Abscission commenced

with basal mature leaves. Leaf areas of plants under drought stress at flowering or pod-filling did not recover after re-watering and seed yield was lower than that of unstressed plants. In conlusion, cowpea can tolerate drought stress at the vegetative stage and recover when water is available at the reproductive stage to produce DM and seed yields equivalent to unstressed plants. Drought stress at the flowering or pod-filling stage reduced yields.

INTRODUCTION

Cowpea (*Vigna unguiculata*) produces seed of high protein content (20% to 40%) for human consumption, and can also be used to increase soil fertility. Estimates of the amout of N fixed biologically by cowpea range from 73 to 354 kg N/ha per year (FAO, 1984) some of which may be available to succeeding crops. Cowpea may be also be grown as a forage legume to provide fodder of higher quality than cereals or forage grasses.

All three benefits may be gained if cowpea is used as a dual-purpose crop for seed and crop residues. However, this would require that pods are harvested green or only partly ripe, because leaf shedding is very pronounced during the later stages of pod ripening, leaving only stems at harvest when pods are completely ripened and dry. As a forage legume, cowpea could provide livestock feed in the semi-arid areas where it is mainly cultivated and which are the major livestock production areas in sub-Saharan Africa. The semi-arid areas are characterised by low and unreliable rainfall, and hence are prone to drought. Water deficits are the main constraint on crop production in these areas (Begg and Turner, 1976).

Many aspects of plant growth are affected by drought stress (Hsiao, 1973), including leaf expansion, which is reduced due the sensitivity of cell growth to water stress. Water stress also reduces leaf production and promotes senescence and abscission (Karamanos, 1980), resulting in decreased total leaf area per plant. Reduction in leaf area reduces crop growth and thus biomass production. Seed production, which is positively correlated with leaf area (Rawson and Turner, 1982) may also be reduced by leaf area reductions induced by drought stress.

For cowpea to be used as a forage or dual-purpose crop in the semi-arid areas, the effect of drought stress on leaf area, and the relationship between leaf area and seed yield, must be understood. Changes in plant water status due to drought stress also need to be investigated, since the growth of a leaf is intimately linked with its water potential.

Since drought may occur at any stage of growth, cowpea was drought-stressed at the vegetative, flowering or pod-filling stages to assess responses of leaf water potential, leaf area and seed yield to water stress.

MATERIALS AND METHODS

Seeds of cowpea were sown in 1:1 mixture of Cornell Mix and sterilised field soil (fine loamy, mixed, non-acid aquic Udifluvents) in 9-litre plastic pots in greenhouses at Cornell University, Ithaca, N.Y., USA. Upon germination, seedlings were thinned to one per pot. Once each week, liquid fertilizer was applied and plants were sprayed against pests and diseases. A 12-hour photoperiod (0600 to 1800 hours) was established using high intensity lamps. Temperature was maintained at 29 ^{o}C during the day and 21 ^{o}C at night. Plants were watered daily during the juvenile stage and twice daily when mature. Drought stress was induced by complete cessation of watering.

Leaf water potentials were measured on young fully expanded leaves using a pressure chamber (Soil Moisture Equipment Corp., Santa Barbara, Ca., USA). To determine the leaf area, lamina length (L) and maximum width (W) of each leaflet was measured with a ruler to the nearest millimeter. Leaf area was then calculated as the product of the length, width and a factor (F) determined for each type of leaflet.

To obtain F, several leaflets were measured by a leaf area meter (Li-3000, Lambda Instruments Corp., Lincoln, Nebraska). Each leaflet area was divided by the product of its length and width. The quotients were then averaged for each type of leaflet, giving F values of 0.67 and 0.71 for for variety TVu 4552; 0.69 and 0.72 for TVu 4954; and 0.49 and 0.54 for TVu 1954-01E for the terminal and the two basal leaflets, respectively. Seed yield and components of yield were determined on plants from which leaves had not been sampled for leaf water potential measurements. When pods started to ripen, watering was curtailed in all treatments to allow pods to ripen and dry. Pods were then harvested, threshed by hand, dried at 55 ^{o}C for 14 days and weighed.

Treatments

In 1982, TVu 4552 was used in three experiments. In the first experiment, plants were stressed at the vegetative stage for 14 days. In the second experiment, watering was stopped for 12 days, beginning 3 days after the first flower opened. Drought stress was imposed at the pod-filling stage in the third experiment; plants were not watered for 12 days, beginning 12 days after the first flower opened. Treatments for 1983 experiments, in which three varieties were used, are shown in Table 1.

RESULTS

Vegetative stage

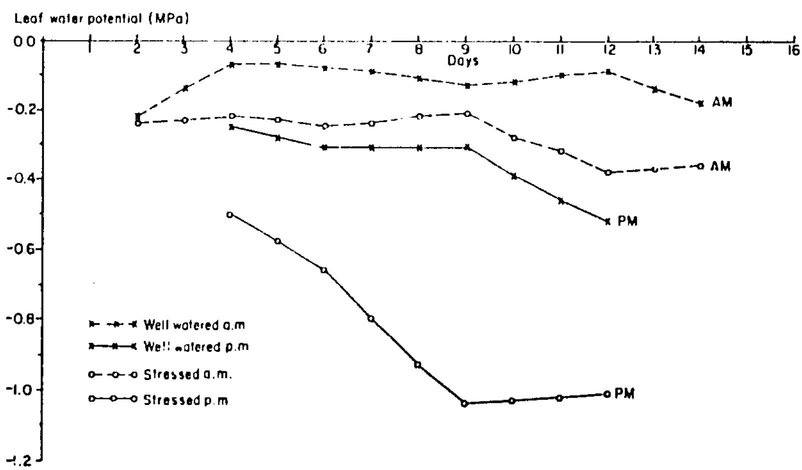
1982: Two days after cessation of watering, the predawn leaf water potential (PLWP) of the drought-stressed plants (-0.22 MPa) was approximately equal to that of unstressed plants (Figure 1). Subsequently, the PLWP of unstressed plants was about -0.1 MPa throughout the 14 days, and the midday leaf water potential (MLWP) declined from -0.25 MPa on day 4 to

Table 1. Experimental treatments.

Growth stage	TVu 1954-01E Period[a]	TVu 1954-01E PLWP[b]	TVu 4954 Period	TVu 4954 PLWP	TVu 4552 Period	TVu 4552 PLWP
Early veg.	23-34	-0.47±0.05	23-34	-0.52±0.02	23-34	-0.49±0.02
Late veg.	30-39	-0.72±0.03	30-39	-0.57±0.53	30-39	-0.59±0.02
Veg.	23-39	-0.54±0.05	23-39	-0.63±0.06	23-39	-0.73±0.02
Control	0	-0.25±0.01	0	-0.23±0.01	0	-0.26±0.01

a. Period without water, days after planting.
b. Predawn leaf water potential, MPa.

Figure 1. *Changes in leaf water potential of TVu 4552 under drought stress at the vegetative stage with time.*

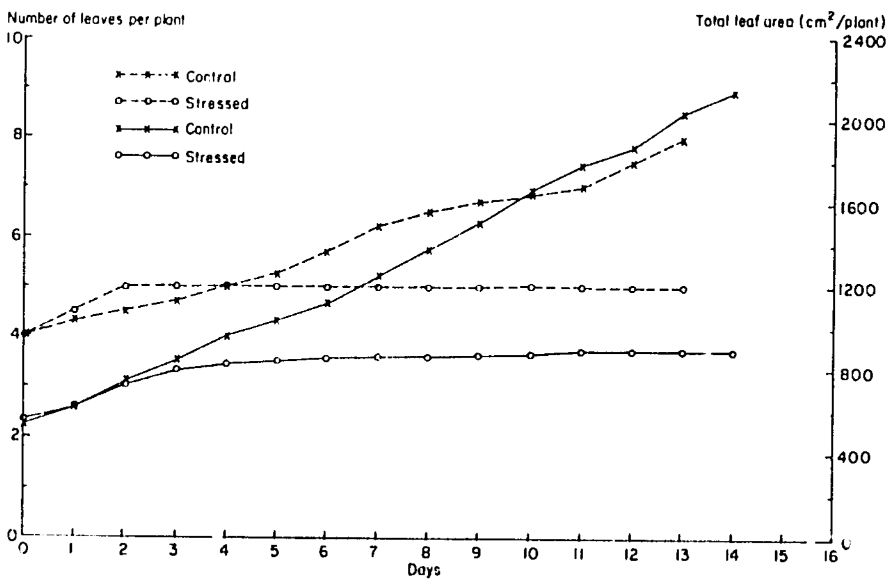


-0.52 MPa on day 12. Predawn leaf water potential of the drought-stressed plants remained fairly constant at about -0.22 MPa until the ninth day, after which it declined to -0.37 MPa 12 days after the last irrigation. However, MLWP of drought-stressed plants decreased linearly from -0.50 MPa on day 4 to -1.0 MPa on day 9.

On average, the difference in PLWP between the drought-stressed and unstressed leaves was less than -0.15 MPa for the first 10 days in the 1982 experiment. Differences between MLWPs of stressed and unstressed plants increased with time and were larger than differences between the predawn values. Differences between predawn and midday values of leaf water potential were larger in drought-stressed than in unstressed plants.

Total leaf area of unstressed plants increased linearly throughout the data collection period because the number of leaves per plant increased from about 4 to 9 (Figure 2). In contrast, leaf growth slowed and eventually stopped in drought-stressed plants. As early as 4 days after irrigation

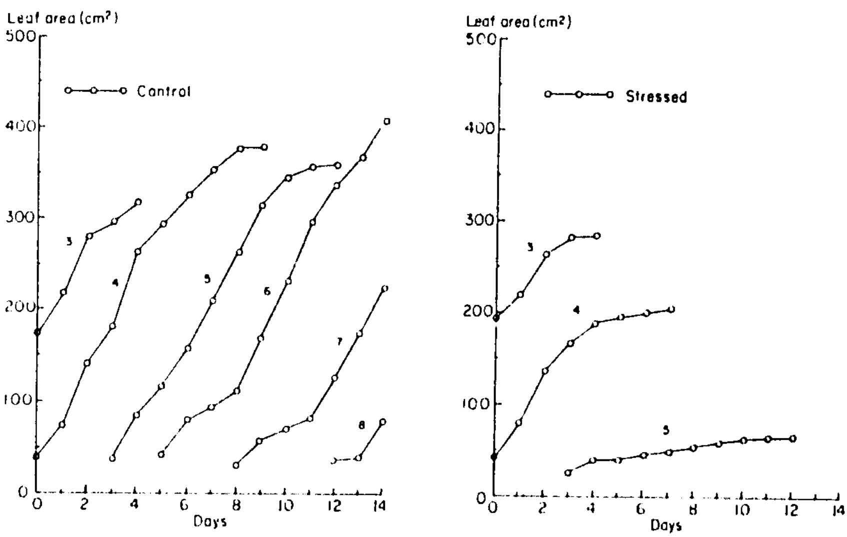
Figure 2. *Changes in total leaf area and number of leaves per plant of TVu 4552 under drought stress at the vegetative stage with time.*



was withheld, the increase in total leaf area of drought-stressed leaves decreased. After day 3, total leaf area of the drought-stressed plants stopped increasing; at the same time, MLWP was considerably lower than in unstressed plants.

The decline in total leaf area was due to cessation of the initiation of new leaves (Figure 2) and a decrease in the expansion of individual leaves. When the drought stress was initiated (21 days after planting), plants were at the fourth or fifth trifoliate leaf stage. Drought stress totally inhibited new leaf initiation after 3 days, resulting in an average of 5 leaves per plant. Figure 3 illustrates the growth patterns of all leaves that were still expanding during the data collection period for both sets of plants. The final area of the drought-stressed leaf 3 was only slightly smaller than the unstressed leaf. The effect of the drought stress was more severe on the growth of leaves 4 and 5. Leaf 5 barely expanded after the initial unfolding; reduction in its area was at least 70%.

Figure 3. *Changes in areas of individual leaves of TVu 4552 under drought stress at the vegetative stage with time.*



1983: Three separate experiments were conducted using varieties TVu 4954, TVu 1954-01E and TVu 4552. Plants were subjected to drought-stress at the early vegetative stage (EV), late vegetative stage (LV) or throughout the vegetative stage (V). Leaf areas were measured at the end of the vegetative stage and at maturity (Table 2).

Table 2. The effect of drought stress at the vegetative stage on leaf area and seed yield of TVu 4552, TVu 1954-01E and TVu 4954. Values are mean ± one standard error of three replicates.

Growth stage	Total leaf area (cm^2/plant) Veg.	Maturity	Number of leaves/plant Veg.	Maturity	Seed yield (g/plant)
TVu 4552					
Early Veg.	1394±101	2158±270	7.7±0.3	13.3±1.3	14.11±1.60
Late Veg.	1615±162	2460±483	8.7±0.7	13.3±1.9	14.89±0.90
Veg.	1064± 62	2258±132	6.3±0.7	15.7±0.9	13.47±1.90
Control	2573±198	3015±250	13.7±1.7	17.0±1.2	18.27±1.67
LSD	533	ns	2.9	ns	ns
TVu 4954					
Early Veg.	1588±204	2181±119	13.3±0.7	18.0±0.50	11.22±0.50
Late Veg.	1676± 82	1815± 73	14.7±1.3	16.3±1.22	12.22±0.38
Veg.	1064± 62	2046±137	12.3±0.9	18.0±0.50	8.07±0.71
Control	2334±235	2315±204	20.0±1.7	21.3±2.2	12.92±0.69
LSD	650	ns	3.9	ns	2.16
TVu 1954-01E					
Early Veg.	1066± 63	2359±414	18.3±1.2	33.7±3.8	14.70±2.55
Late Veg.	1630± 93	2657± 60	23.7±1.2	37.0±1.2	16.32±1.08
Veg.	633±106	2552±403	14.7±0.3	35.3±3.4	13.36±0.77
Control	2169± 77	3201±337	31.0±1.5	43.0±1.5	16.39±3.27
LSD	290	ns	4.2	ns	ns

At the end of the vegetative stage, leaf areas of the drought-stressed plants were significantly smaller than those of unstressed plants (Table 2). Upon re-watering, drought-stressed plants resumed growth. At maturity, differences in leaf area between the drought-stressed and unstressed treatments was not significant.

In TVu 4552, seed yields of all drought-stressed treatments were not different from each other and were lower than the control. However, this difference was not statistically siginificant. The regression of leaf areas at the end of the vegetative stage and seed yield at maturity was significant ($r = 0.77$, $P<0.01$) and was described by the equation: Yield = 9.2 + 0.004 (Leaf Area).

The seed yield of TVu 4954 plants subjected to drought-stress throughout the vegetative period (treatment V) was significantly lower than that of unstressed plants. The regression of leaf areas at the end of the vegetative stage on seed yield was: Yield = 5.61 + 0.003 (Leaf Area), and was significant ($r = 0.82$, $P<0.01$). The regression of leaf areas at maturity on seed yield was not significant. For TVu 1954-01E, neither the leaf area at the end of the vegetative stage nor at maturity was significantly correlated with seed yield.

Flowering stage

For the first 11 days of the drought period at the flowering stage, PLWP of stressed plants remained within 0.15 MPa of that of unstressed plants (Figure 4). During this period, leaf water potential of the drought-stressed plants declined by only 0.1 MPa, from -0.12 MPa to -0.22 MPa.

During the flowering stage, the leaf area of unstressed plants remained fairly constant. Three days after the imposition of drought stress at the flowering stage, leaf area increment began to diminish (Figure 5). After day 4, total leaf area began to decline. Over the 12-day period, total leaf area of the drought-stressed plant declined by about 40%, mainly due to loss of leaves. Changes in the

Figure 4 *Changes in leaf water potential of TVu 4552 under drought stress at flowering stage with time.*

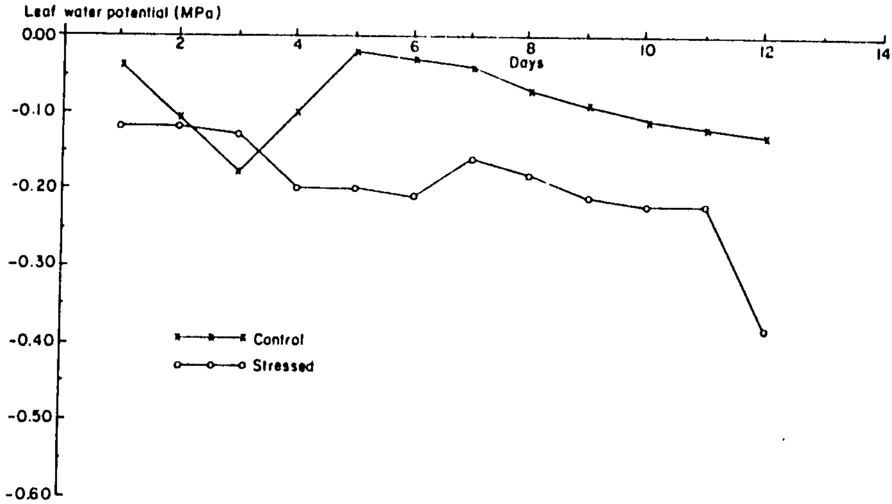
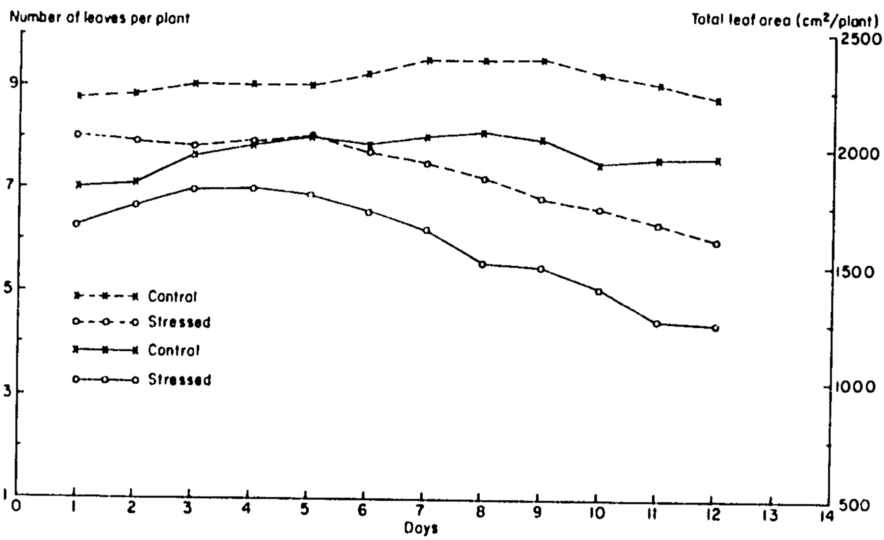


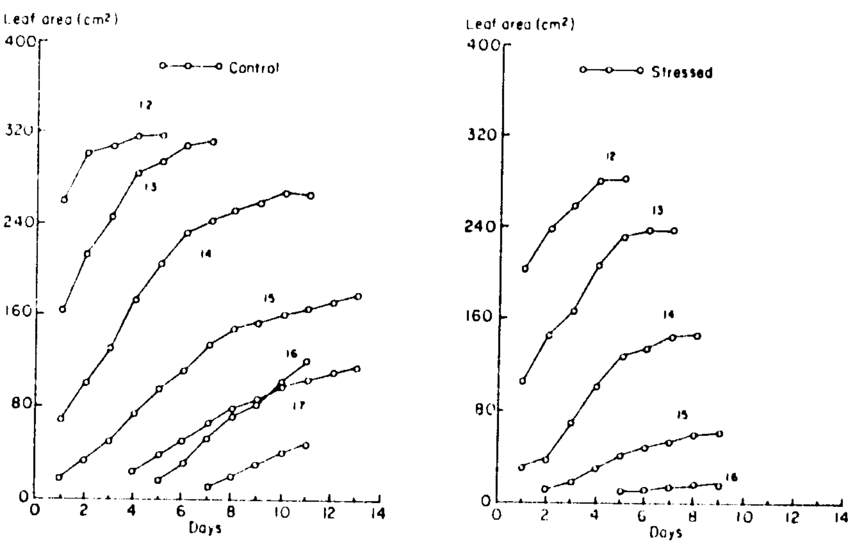
Figure 5. *Changes in total leaf area and number of leaves per plant of TVu 4552 under drought stress at flowering stage with time.*



total leaf area of the drought-stressed plants were the result of changes in the number of leaves per plant and in leaf expansion. The treatments were imposed 2 days after the first flower opened, when plants were at the 13- to 15-leaf stage. Due to injury from pesticide application at the vegetative stage, the lowest five or six leaves of each plant had abscissed. Most of the unstressed plants added one or two new leaves during the course of the experiment, but also lost mature basal leaves, which left an average of nine leaves per plant. Drought-stressed plants also exserted a few new leaves but could not retain the older ones after 4 days of drought-stress. On average, only six leaves remained per plant at the end of the drought phase.

In addition to the loss of leaves, the expansion of individual leaves slowed and stopped in stressed plants. Growth patterns of individual leaves at the flowering stage are illustrated in Figure 6. The oldest leaf that was still expanding at the beginning of the treatment was that at node 12. Drought stress inhibited the growth of all leaves and caused delays in the exsertion of leaves 15 and 16.

Figure 6 *Changes in areas of individual leaves of IVu 4552 under drought stress at flowering stage with time.*



Drought stress significantly reduced seed yield due to a reduction in the number of pods per plant (Table 3). Individual seed weight was significantly higher in the drought-stressed treatment but did not compensate for the loss in pods. Leaf area measured at the end of the drought-stress period was highly correlated with seed yield. The regression equation was:

$$\text{Yield} = 2.9 + 0.008\ (\text{Leaf Area}) \quad (r = 0.90,\ P<0.01)$$

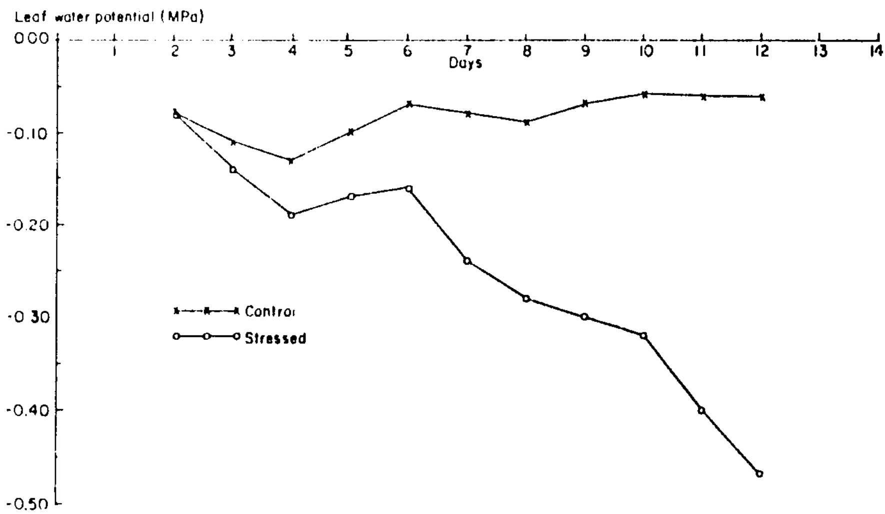
Table 3. The effect of drought stress at the flowering or pod-filling stage on leaf area and seed yield of TVu 4552. Values are mean ± one standard error of four replicates.

Treatment	Leaf area (cm^2/ plant)	Seed yield (g/ plant)	Pods per plant	Seeds per pod	100 seed wt. (g)
Flowering stage					
Control	1956±280	19.4±2.6	15.8±0.8	9.7±0.9	12.8±2.3
Stress	1167±101	13.0±1.8	11.3±0.6	8.1±0.8	14.8±3.6
LSD (0.05)	649 (0.10)	4.5	2.8	NS	1.4
Pod-filling stage					
Control	1478±180	5.6±1.2	5.5±0.9	8.0±0.9	12.7±1.1
Stress	748±184	4.0±0.7	3.3±0.3	7.0±0.2	14.9±0.5

Pod-filling stage

Predawn leaf water potential of the drought-stressed plants declined gradually to -0.48 MPa on the 12th day, when stress was terminated (Figure 7). However, it was not until the 7th day of drought that the difference between stressed and unstressed leaves was larger than 0.15 MPa. Unstressed leaves had PLWPs of about -0.10 MPa.

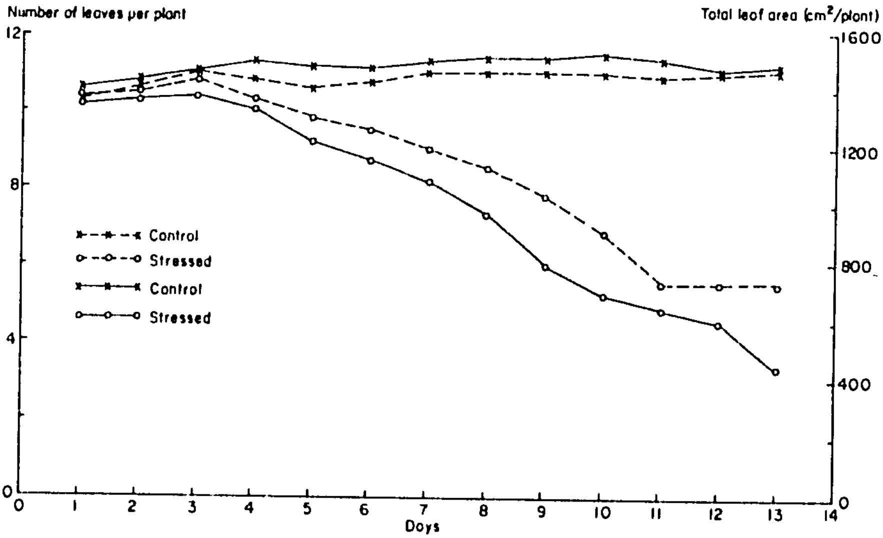
Figure 7. *Changes in leaf water potential of TVu 4552 under drought stress at pod-filling stage with time.*



Total leaf area started to decline 3 days after the cessation of watering at the pod-filling stage, and continued to decline until the last day of the drought period (Figure 8) because of leaf abscission. Total leaf area of unstressed plants remained constant.

Approximately 10 leaves were present on each plant at the beginning of the treatments at the pod-filling stage (Figure 8). This number increased to about 11 in both treatments. Leaf senescence and abscission reduced the number of leaves on drought-stressed plants to about six. Although unstressed plants initiated a few new leaves, basal mature

Figure 8. *Changes in total leaf area and number of leaves per plant of TVu 4552 under drought stress at pod-filling stage with time.*

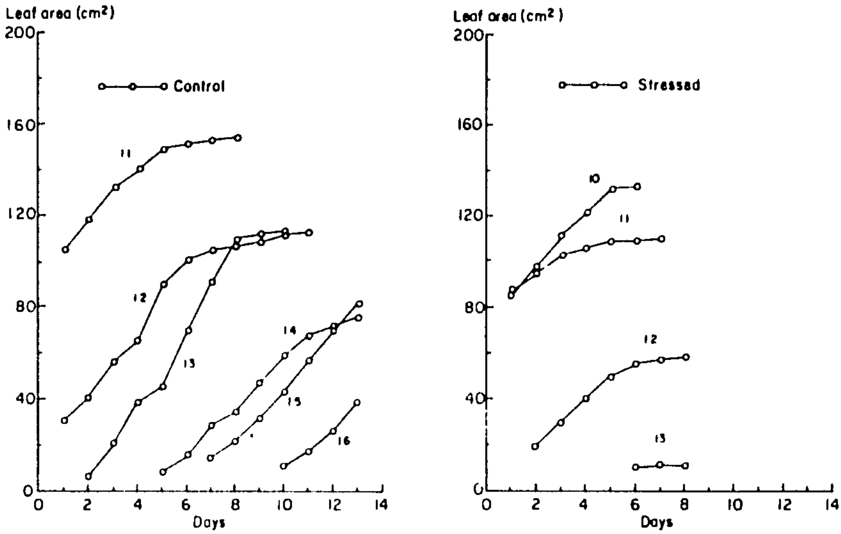


leaves abscissed. Thus, a constant number of leaves was maintained.

The new leaves expanded to smaller final sizes, as indicated by the decreasing sizes of the higher numbered leaves (Figure 9). One drought-stressed plant did not put out any new leaves and all its leaves ceased expanding immediately after the drought stress was imposed. Drought-stressed leaves were smaller than the unstressed leaves.

Leaf abscission was more important than cessation of leaf expansion in determining final leaf area. Total leaf area of drought-stressed plants was only 50% of that of unstressed plants (Table 3). Seed yield and number of pods per plant, even of unstressed plants, were extremely low. The regression of leaf area on seed yield was significant ($P < 0.10$), with a correlation coefficient $r = 0.64$.

Figure 9. *Changes in areas of individual leaves of TVu 4552 under drought stress at pod-filling stage with time.*



DISCUSSION

During drought stress, cowpea maintained fairly constant PLWP at a level not much lower than that of unstressed plants. Turk and Hall (1980) also showed small differences between the leaf water potential of stressed and unstressed cowpea even after 43 days without irrigation. Drought-stressed plants occasionally had higher leaf water potentials than well-watered plants.

This behaviour of cowpea is unlike crops such as soya bean (Wien et al, 1979; Villalobos-Rodriquez and Shibles, 1985) and maize (Lal et al, 1979), in which large differences in leaf water potential were found between drought-stressed and unstressed leaves. The constancy or slow decline in PLWP suggests that cowpea can conserve water. An explanation for this behaviour may be found in the changes in leaf growth that limited evaporative water loss (Akyeampong, 1985): Leaf exsertion, expansion, and abscission were sensitive to drought stress at the vegetative, flowering or pod-filling stage.

At the vegetative stage, drought stress initially reduced the rate of leaf expansion, followed by a cessation of new leaf production. Eventually, leaf area increment fell to zero. No leaves were lost, however. Stressed plants remained in a stunted state until they were re-watered (Warrag and Hall, 1985). In addition to the cessation of expansion of leaves and inhibition of production of new leaves, drought stress at the flowering or pod-filling stage caused the senescence and abscission of mature basal leaves. Only mild stress is required for the abscission of mature leaves (McMichael et al, 1973). At the vegetative stage, no leaves were lost, even when the PLWP was -0.40 MPa, which was lower than the PLWP on day 4 of the flowering (-0.2 MPa) or pod-filling (-0.18 MPa) treatments when pods were lost. The number of leaves per plant, and hence the total leaf area per plant, was reduced when plants were stressed at the flowering or pod-filling stage.

Drought stress thus reduced evaporative surface area, which would reduce transpiration. Extensive leaf movements to minimise the interception of radiation (Shackel and Hall, 1979) and the reduction in stomatal conductance (Akyeampong, 1985) also reduce transpiration in cowpea under drought stress (Akyeampong, 1985; Hall and Schulze, 1980). Other suggested mechanisms that cowpea uses to maintain plant water status are: (a) increased root density and depth during stress to exploit a larger volume of soil, (b) a decrease in plant resistance to water movement as the level of stress increases, to allow for the replenishment of lost water (Wien et al, 1979) and (c) mechanisms which result in only slow extraction of soil water as soil begins to dry (Turk and Hall, 1980). Such mechanims ensure the survival of the crop during drought.

The cessation of leaf expansion at a high leaf water potential indicates that cowpea leaves are acutely sensitive to drought stress. Leaf expansion was probably influenced more by daytime than by predawn leaf water potential. Midday leaf water potential declined progressively with time. The reduced moisture status of the the leaves deprived the cells of the forces for expansion and thus slowed leaf expansion. Cell division, considered to be less sensitive to drought stress than cell expansion (Hsiao, 1973), may have been inhibited later as stress increased.

Equally, if not more, important from the point of view of the use of cowpea as either a forage or grain crop, were observations of the growth of cowpea subsequent to re-watering. After re-watering, plants that were stressed at the vegetative stage resumed growth and leaf area recovered completely, providing large amounts of vegetative material that could be used as feed. Leaf growth during the recovery phase was not at the expense of seed-filling (Fischer and Hagin, 1965), and drought-stressed plants yielded as well as those that had been well-watered throughout. Cowpea recovers from drought stress at the vegetative stage, provided that favourable climatic conditions prevail during the post-stress period (Shouse et al., 1981).

In contrast, the detrimental effect of drought stress at the flowering or pod-filling stage was not alleviated by re-watering. When the plants were re-watered at the flowering stage, reproductive activity resumed, but most of the new pods failed to reach maturity due to inadequate resources, the result of excessive leaf loss. Presumably, photosynthate was used to support leaf growth in this more-or-less indeterminate variety, to the detriment of pod-filling (Fischer and Hagin, 1965).

In contrast to drought-stressed plants, growth of leaves on the unstressed plants continued through the pod-filling stage, but total leaf area did not expand much during the flowering and pod-filling stages due to three factors. Firstly, only a few leaves were exserted after flowering. Secondly, some of the mature leaves near the base of the plants were lost. Finally, although duration of the expansion of unstressed leaves was about equal at all stages of growth, individual leaf expansion rate was low during the flowering and pod-filling stages. Hence new leaves were smaller, adding little to leaf area.

These results have important implications for the management of planting (and irrigation, where feasible) of cowpea. To avoid severe yield (seed and total biomass) losses, planting should be done at such a time that the critical stages (flowering and pod-filling) would coincide with the period when water is most available.

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FORAGE LEGUMES
IN PRODUCTION SYSTEMS

THE ROLE OF LEGUMES IN FARMING SYSTEMS OF SUB-SAHARAN AFRICA

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ABSTRACT

Legumes have played an important role in raising productivity of farming in the temperate zone. The challenge is to demonstrate a similar role for the tropics. The primary role of legumes is in fixing atmospheric N_2 leading to their capacity to (1) build soil fertility and (2) enhance forage and mulching quality.

Ecologically, legumes are largely species of successional habitats and thus, to maintain stable legume-based associations, management is a necessary input. The effectiveness of legumes in biological N_2 fixation is very variable, depending on environmental, nutritional, biological and genetic factors. Therefore, their effect on soil fertility is also likely to be variable and substantially under management control.

The contribution that legumes can make to herbage quality is considerable and there is ample evidence of substantial gains in animal production being possible. They also have high mulching value for crop production. Farming systems in most of sub-Saharan Africa are substantially different to those in Australia or much of tropical America. In most of Africa, small-scale, mixed crop-livestock farming systems are the norm, with the two components being closely integrated. In a variety of such systems legumes are being found that can be integrated into both the crop and the livestock component. In systems with minimal fertilizer inputs, legumes can contribute to the crop phase by reducing

the rate of soil fertility decline, or even enhancing crop yield, as well as reducing the length of the fertility-regenerating fallow period. In the pastoral phase, legumes contribute to better quality and use of crop residues and of natural forages on fallow lands. A variety of farming systems are discussed for the humid, subhumid and semi-arid agro-ecological zones.

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

INTRODUCTION

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

THE ROLE OF LEGUMES IN FARMING SYSTEMS

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

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

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

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

BIOLOGICAL NITROGEN FIXATION

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

It is not surprising, therefore, that measurements of the amounts of N fixed vary quite widely. Haque and Jutzi (1984) tabulated some fixation rates from different parts of Africa for a range of legume species (Table 1). These values range from 34 to 395 kg N/ha, with four species averaging over 200 kg/ha. Mannetje et al (1980), in their review, quote values of 47 kg N/ha per year over a 26-year period on temperate Australian *Trifolium subterraneum*, 30 kg N/ha per year over a 10-year period on a grazed *Stylosanthes humilis-Heteropogon*

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

Legume	Range (kg/ha/year)	No. of records
Centrosema pubescens	84-395	3
Desmodium uncinatum	178	1
Leucaena leucocephala	110-600	4
Stylosanthes guianensis	94-290	3
Trifolium semipilosum	80	1

Source: Haque and Jutzi (1984)

cortortus pasture in the tropics and 280 kg N/ha in 4 months from *Centrosema pubescens* in sand culture in Malaysia.

These results indicate that, over a wide range of conditions, legumes can fix significant but varying amounts of N. However, these amounts need to be equated over time because varying proportions are cumulative in different soil compartments. This is also an important consideration because N may accumulate in the soil in organic, biological or inorganic (NO_3, NH_4^+) forms. In some situations (e.g. heavy clay soils), total N fertility may increase steadily whilst available N fertility declines because of the build up of micro-organisms that compete successfully for available N. Eventually a situation is reached where the high-fertility soil becomes apparently as infertile as an inherently low-fertility soil. Studies by Mohamed-Saleem and others (this volume) indicate that plant responses to the build-up of soil fertility are not accounted for by N levels alone. It appears that the effects on overall soil biology, in terms of lower bulk density, higher infiltration rate and more rapid nutrient turnover, are important.

EFFECTS OF LEGUMES ON HERBAGE QUALITY

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

Because of the initially higher levels of protein in the legume tissues, it takes longer for their protein content to fall to less than 6.5%, the lower protein threshold for

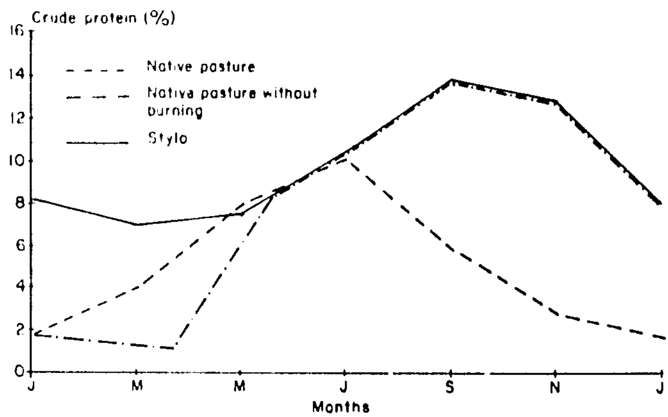
Table 2. Quality components of forages grown under identical controlled environments.

	Temperate legume	Tropical legume	Tropical grass + N
Crude protein (%)	23.5	21.2	12.2
Dry matter digestibility	76.4	72.8	70.5

Source: Mannetje et al (1980).

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

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



Source Mohamed-Saleem (1985)

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

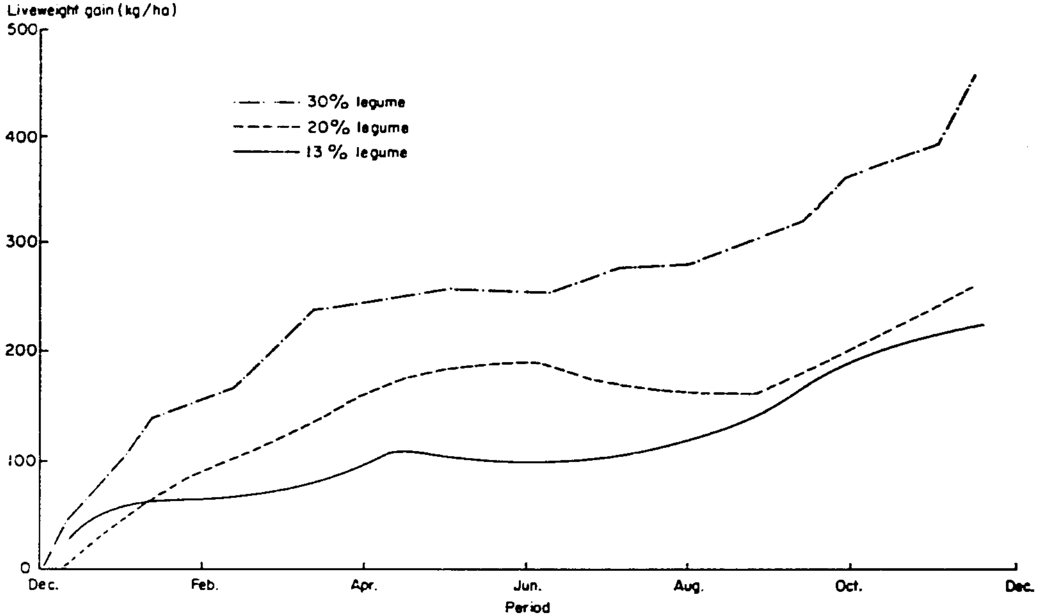
The use of forage legumes as intercrops, relay crops, or live-mulch cover crops relies on the ability of the legume to supply N to an associated or subsequent crop. All of these applications are essentially still at early experimental stages (Powell, 1985; Mohamed-Saleem, 1985), although intercropping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

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

INCREASING ANIMAL PRODUCTION

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

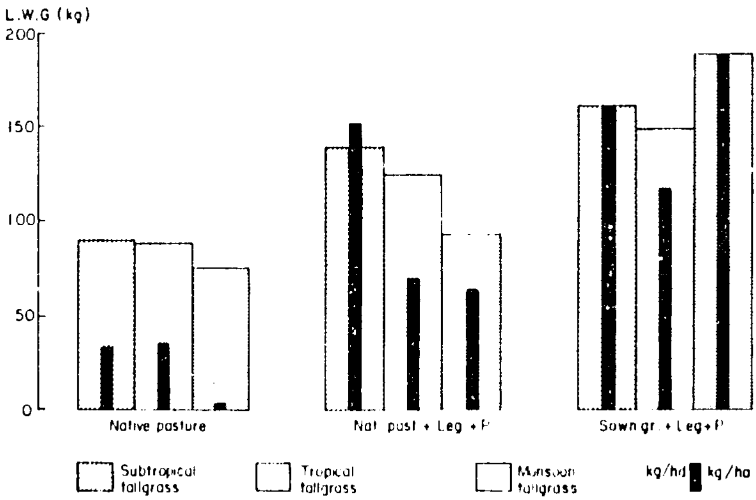
Figure 2. *The effect of legume content on liveweight gain of steers.*



Source: After Evans (1982)

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

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

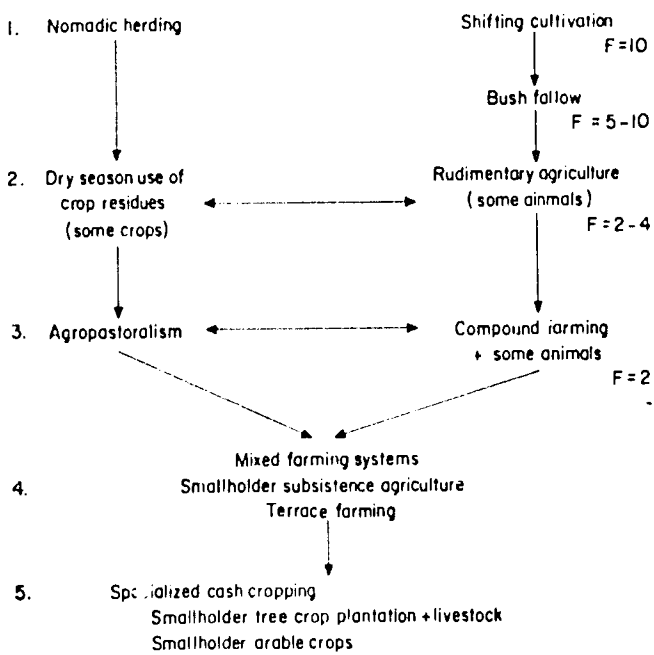


Source: Tothill et al (1985).

FARMING SYSTEMS IN AFRICA

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

Figure 4. *Farming systems in Africa*



However, as population pressure increased, the length of time that land was fallowed decreased. This in turn depleted the fertility of the soil, reducing crop yields and the length of the cropping phase in the rotation. As a result, agricultural systems have been encroaching on the traditional dry season grazing lands for some time, because these tended to be on soils with higher residual water content or better fertility. System 4 (Figure 4) is a natural consequence of the meeting of these two distinct farming systems which is both contemporary, as in much of West Africa, and quite old, as in Ethiopia and Burundi. The most widespread system in the more heavily populated regions of sub-Saharan Africa is the smallholder, mixed-farming system.

In West Africa the separation between the extensive pastoral and arable farming systems is now substantially less than before and most systems now include livestock. Indeed, the strong correlation between crop production and livestock production in Ethiopia indicated by Gryseels and Getachew (1985) is likely to be fairly general throughout Africa. This relationship exists because of the role that crop residues play in the dry season feeding of livestock and the complementary role that animals play in providing traction, manure and producing human food from crop residues and forages from rough grazing lands of no alternative value. Even so, crop residues cannot sustain most animals adequately throughout the dry season and there is therefore a need for forages that improve livestock nutrition during this period.

Legumes show promise in being able to provide better quality feed during the dry season, and have the additional benefit of helping to restore soil fertility depleted by more intensive cropping. Legumes could be included either within the cropping phase, to reduce the rate of soil fertility depletion, or during the fallow phase, to speed up the fertility restoration rate.

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

The humid zone (> 1100 mm average annual rainfall)

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

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

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

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

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

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

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

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

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

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

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

The semi-arid, Sudano-Sahelian zone (<800 mm average annual rainfall)

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

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

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

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

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

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

SUPPLEMENTING RESIDUES AND BYPRODUCTS WITH LEGUMES

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

MANAGEMENT OF LEGUME-BASED INTERVENTIONS

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

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

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

Management and soil fertility

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

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

Management and palatability

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

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

Management and demographic/phenological factors

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

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

Socio-economic factors

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

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

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

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

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INTEGRATION OF CEREAL-LIVESTOCK PRODUCTION IN THE FARMING SYSTEMS OF NORTH SYRIA

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ABSTRACT

Integration of cereal and livestock enterprises in existing farming systems is based on utilisation by livestock of green cereal plants, straw and grain. The quality of local barley straw is very high and experiments have shown that sheep are able to maintain liveweight on a diet of straw alone. Straw of new varieties is of inferior but variable quality and it is possible to select for improved straw quality without decreasing grain yield. Farmers believe that green-stage grazing increases, or at worst does not decrease, grain yield, but this is not supported by experimental evidence, possibly because grazing pressures imposed by farmers are less severe than those imposed by researchers.

Current livestock farming systems rely on grazing marginal lands. The possibility of replacing this grazing by use of fallows in cereal/fallow rotations is discussed under two headings: leguminous forage crops and self-regenerating pastures. The most important problems associated with forage crops are costs of sowing and harvesting, and the results of recent on-farm experiments which study the possibility of direct grazing are examined. It is suggested that both green-stage and mature-crop grazing are cheaper than hay or straw making, but in the case of mature-crop grazing it may be important to select cultivars with non-shattering seed pods.

Cereal yields after forage crops are higher than after cereals and as good as after fallow, but the evidence suggests that increased availability of N is not important. In spite of increasing forage yields, including cereals in mixtures with forage legumes is detrimental to subsequent cereal yields and should not be recommended.

Ley farming (replacing fallows with self-regeneration annual pastures) is an attractive new alternative to fallow, but is not used commercially in the region. Reasons include technical problems, attitudes of ley-farming experts and lack of seed. Many of the technical problems have now been resolved but the economic value of ley-farming in the region and at the farm level remains to be proven. If seeds of adapted pasture cultivars become widely available it seems likely that ley farming will have a large impact on cereal and livestock production.

The paper concludes with a few comments on the use of pastures and forages in the Ethiopian highlands.

INTRODUCTION

It has been suggested that, in developing countries, the ability of middle-income people to buy livestock products is one of the reasons for hunger among people with low incomes. The argument is that livestock are competitors for cereals, the cheapest form of energy and protein. To help resolve competition for cereals in favour of people with low incomes, Yotopoulos (1984) suggested that livestock products should be taxed to reduce demand by increasing their price. While it is true that some livestock do rely heavily on cereals, in many instances this is not or need not be so. Indeed it is possible that a tax would have the opposite effect to that which Yotopoulos seeks: livestock would stop using land that cannot be used to produce cereals and, more importantly, cereal byproducts would be wasted, and the beneficial effects of integrating livestock and cereals would be lost. In the following discussion I will elaborate on this point of view.

The term 'integration' is used in this paper to describe the process by which farmers produce cereals and livestock to the mutual benefit of each enterprise. I will emphasise farming in north Syria but as often as possible will refer to other parts of the Mediterranean region, especially North Africa. I will conclude with a brief reference to integrated livestock/cereal farming in the highlands of Ethiopia.

Syria is officially divided into five agro-ecological zones, roughly coinciding with humid (zone 1), semi-humid (zone 2), semi-arid (zone 3), arid (zone 4), and very arid (zone 5) Mediterranean climates (Pabot, 1956). Livestock are produced in parts of zone 2, and in zones 3, 4 and 5, while cereals are grown in zones 1, 2, 3 and 4. Excluding zones 1 and 5, where livestock and cereals are not produced together, average rainfall varies from about 200 mm (the lower limit of zone 4) to 350 mm (the upper limit of zone 2). Livestock increase in importance relative to cereals as rainfall decreases.

Sheep are the preferred livestock species in Syria, there being 12 million sheep in 1982 compared with between 600 000 and one million goats and 250 000 to 400 000 cattle. There are very few cattle in zones 3 and 4: they are concentrated in irrigated areas around Damascus and Homs, and along the coast. Of the cereal species, barley is preferred in zones 3 and 4, and wheat in zone 2.

The discussion in this paper is confined to integration of sheep and cereal enterprises in zones 2, 3, and 4, with references to other regions.

THE NATURE OF INTEGRATED LIVESTOCK/CEREAL FARMING SYSTEMS IN SYRIA

With the exception of part of zone 1 and zone 5, Syrian farmers are cereal growers, livestock using crop byproducts, weedy fallows and common (non-arable) land. Only in dry areas do farmers focus on livestock and even there at least half of the farm is used to grow cereals. Cropping frequency, if it followed the official agricultural plan, would decrease as rainfall decreases, such that all the land in zone 1 would be cultivated each year compared with only 30% (barley followed by two years of fallow) in zone 4. In fact what is happening is increased cropping intensity in all zones, even in zone 4 where on some farms all the land is cultivated each year.

Farmers in wet areas can choose from several crop species, and most farmers sow cereal (usually wheat) after fallow or summer crop, the latter growing in summmer on residual soil water. Where included in rotations, lentils or chickpeas follow cereal, but the area allocated to food legumes exceeds 5% only in zone 1, where they occupy 18% of the land.

Sheep farmers produce three products, milk, meat and wool, accounting for 30, 60 and 10%, respectively, of gross income (excluding trading in ewes). Mating is from June to August and lambing begins at the end of October and continues until April or May if the ewes were in poor condition at mating. Lambing rates vary from 50 to 100% of ewes mated (with a mean of 85-90%) and lamb mortality is 5-15%. Milking commences about 60 days after lambing and, until lambs are weaned, the ewes suckle the lambs at night, are separated from the lambs during the day, and are milked in the afternoon. Milk production varies from 50 to 100 kg per ewe. Production from goats is similar, although the kidding rate is a little higher.

Little grazing is available in winter although many flocks may be seen grazing rangelands and roadsides on fine days. Supplementary feeding usually ends between February and April, depending on the season and environment, and during spring flocks graze common lands and fallows, their diet often supplemented with weeds that are hand pulled from crops. In wetter districts cereals may be grazed lightly, and in drier areas and during droughts failed crops are grazed heavily in late spring. Stubbles are grazed until October, depending on season and locality, at which time supplementary feeding begins. Barley grain and straw are the most important supplements, but wheat and lentil straw and cotton byproducts are also fed.

Near Aleppo, flock size varies between 50 and 300 head and farm size from 3 to 30 ha with a few larger farms (FSP, 1980). Income from livestock varies from 10 to 50% of total farm income, although in some dry areas the cereal from the farm is used for feed. Supplementary feeding is the most significant cost faced by livestock producers. In 1977/8, village-level studies indicated that net income varied from SL 56 per ha to SL 104 per ha (US $ 1 is approximately equal to SL 11): these figures can probably be increased by 300% to account for inflation since the study was made.

Livestock and cereal enterprises are integrated in three ways. Firstly, livestock are bought with surplus cash when crops are sold and are sold when cash is needed. Secondly, livestock use crop byproducts, especially straw, stubble and weeds, which would otherwise have no value. In this context the importance of stubble grazing as a prerequisite for land preparation should not be overlooked. Thirdly, ownership of livestock allows farmers to use land resources, especially hills and shallow, stony soils, which cannot be used for growing cereals.

In attempting to increase farm productivity through improved integration of cereal and livestock enterprises, I will discuss first the potential for improving the use of cereals for grazing and straw, and secondly ways of using fallows for livestock production. The latter discussion will be divided into two: growing leguminous forage crops, and establishing self-regenerating pastures. The discussion is not intended to cover the whole subject and will focus on the research at ICARDA.

CEREALS AS A SOURCE OF FEED

There are three ways of using cereals to feed livestock: they can be grazed at the green stage, the grain itself can be used, and straw or stubble is an important source of animal feed. Beyond commenting that in dry areas barley provides up to 50% of nutritional requirements of livestock at present, I will not discuss further the role of grain in integrating livestock and cereal production. Indeed the point made by Yotopoulos (1984) regarding competition between humans and animals for cereals has some validity in this respect although in Syria barley is not normally used by humans.

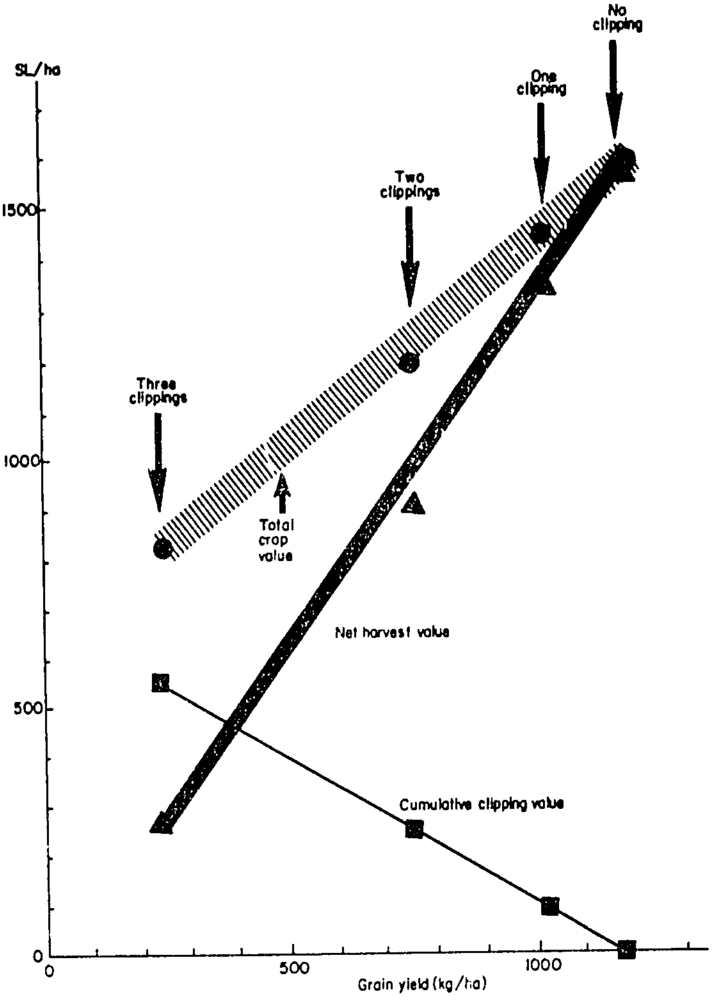
In spite of widespread farmer belief to the contrary (FSP, 1980) all experiments indicate that grazing cereals causes a substantial reduction in grain yield even in the most favourable environments. For example, in 1981/82 yields of barley at Tel Hadya (ICARDA headquarters, about 40 km south of Aleppo) were reduced by 20-40% after grazing in mid-February: available dry matter at the time varied from 1.4 to 2.03 t/ha, depending on variety, compared to 0.8 t/ha obtained by Droushiotis (1984) in a similar experiment in Cyprus. The question is, how much are the benefits of winter grazing offset by lower grain yields?

The evidence indicates strongly that winter grazing is not profitable. In an experiment conducted at Breda, fairly typical of barley producing areas in north Syria, it was found that the more barley was grazed the lower was its total value, even when the value assigned to winter dry matter was twice that of grain (Figure 1). Why then do many farmers continue with a practice which appears to cost them so dearly?

The answer may lie in the different grazing techniques used by farmers and experimenters: Where grazing is widely practiced, surveys have revealed that it may be done earlier in winter and more lightly than in the experimental crops. Allden (1980) quotes data on time and intensity of grazing which appears to support this view. Or it may simply be that farmers place great value on maintaining sheep in good condition and will do so regardless of cost. But in the sense that integration refers to complementation between cereals and livestock it appears that winter grazing is not a powerful force and may even be detrimental.

The use of straw however is another matter: recent work

Figure 1. *Effect of clipping on the total value of barley crops.*



has shown that up to one-third of the metabolisable energy requirements of sheep in winter comes from barley straw (Table 1). Straw is so important that any increase in grain yield must take into account its effect on straw yield and quality. In this sense, much recent plant breeding work, which has resulted in improved harvest index with no consideration of straw quality, is open to serious criticism.

Table 1. Contribution of various feedstuffs to the diets of sheep (percentage of total diet) from November to February (mean of 2 years).

	Dry matter %	Metabolisable energy %	Protein %
Barley straw	49	37	20
Barley grain	22	29	27
Cottonseed cake	5	7	19
Wheat straw	7	9	12
Other grains and straw	7	8	10
Other concentrates	10	10	12

Source: R. Jaubert and M. Oglah (personal communication).

This need not be so. As a result of work by Capper and his colleagues (Capper et al 1985a; 1985b) it is becoming increasingly clear that grain yield can be increased without reducing straw quality. Although there are very few (if any) improved barleys with straw quality as good as local landraces, Capper's data suggest that there is a large variation in straw quality within barley and that this is not related to yield. Furthermore, his work lends strength to the low opinion held by farmers of straw in temperate environments: straw of cereals grown in the United Kingdom was of markedly lower quality than straw in Syria.

Apart from Arabic Abiad (a local barley), Capper found that no variety provided sufficient nutrients to maintain liveweight. The problem is protein deficiency: addition of protein to straw diets resulted in liveweight gains of more than double those which followed addition of energy (ICARDA, 1985). In contrast, Allden (1980) concluded that in dry pasture residue there were deficiencies of both energy and protein. Allden further points out that, in the environment in which he worked (southern Australia), cereal straws and stubbles are considered to be of such poor quality that very little research on their nutritional value has been carried out or indeed is thought necessary.

Grazing of stubbles probably has another beneficial effect on crop establishment. In north Syria tillage operations begin before or soon after the first rains. Straw impedes cultivation, especially if some form of shallow cultivation is desired. A few farmers burn their stubbles but most use grazing in residue management. This has many of the advantages of conservation tillage, developed recently in the United States (Allmanas and Dowdy, 1985). In this system, straw is left on the surface of the soil, so reducing wind erosion and avoiding problems associated with biological degradation of straw incorporated into the soil (reduced availability of mineral N). Residue management in the United States needs special machinery: this too is avoided by stubble grazing.

Straw utilisation is therefore a good example of cereal/livestock integration, with each enterprise enhancing the other's profitability. By selecting cereal varieties with high straw quality and yield it should be possible to increase livestock production from this important component of integrated farming systems.

INTEGRATION THROUGH REPLACEMENT OF FALLOWS WITH FORAGE CROPS

Forage crops are defined as leguminous crops sown and harvested in a single year which do not re-seed themselves. They are harvested as hay or straw and, as will be seen later, can also be grazed. Forages are not used extensively: in north Syria about 8% of zone 1 is used for crops of *Vicia sativa* and *V. ervilia*, and in zone 2 about 5% of the deeper soils are used for *V. sativa*.

This is an under-estimate of the number of crops used as forage. Barley is often grazed at the green stage or near maturity: lentil (*Lens culinaris*) also produces straw of great feeding value and is grazed during spring when seasonal conditions suggest that grain yield will be low. At Tel

Hadya the 20 highest yielding lentils had an average biological yield of 9.1 t/ha, compared with only 7.8 t/ha from field peas grown for forage nearby (Erskine, 1983; Ceccarelli and Somaroo 1981, respectively). Lentils are grown in zones 1 and 2.

In view of the huge diversity of legumes in the Mediterranean region, surprisingly few have been used specifically as forage crops. Kernick (1978) notes that three species of *Lathyrus* and nine species of *Vicia* are potentially important, but of these probably only nine species have been tested and fewer still used. In north Syria only *Lathyrus sativus* (where rainfall < 300 mm), *V. ervilia* (> 400 mm), and *V. sativa* (300-500 mm) are actually grown, *L. sativus* only on very small areas. There are several other species, most notably *Pisum sativum* (Keatinge et al, 1984), and possibly *Scorpiurus muricatus*, some annual *Trifolium* spp, and *Medicago scutellata* that have received limited testing.

To be successful, forages need high inputs of seed, fertilizer, and labour. The costs of these inputs make forage legumes poor competitors with alternate forms of land use (Tully, 1984). For example, at least 100 kg of *V. sativa* seed/ha is necessary for maximum forage yields in Cyprus (Hadjichristodoulou, 1975), Syria (ICARDA, 1984) and Morocco (Villax, 1963), and fertilizer rates of 18-26 kg of P/ha and 20 kg N/ha are recommended, the latter when legumes are mixed with cereals (Kernick, 1978). The absence of hay-making machinery and the high cost of hand harvesting also make forages unattractive in many countries.

The use of crop mixtures is of special interest. In most cases, adding a cereal increases yield and makes harvesting easier but there are two biological costs: Nitrogen fixation is reduced, and the effect as a break crop may be nullified. Hadjichristodoulou (1975) observed that yields doubled when barley was added to *V. sativa*, *V. villosa*, and *P. sativum*. However, his treatments, which included applying 20 kg N/ha, did not measure the effect of the mixtures on subsequent cereal yields. This has been done by Osman and Nersoyan

(1985), who found that even 33% cereal in the mixture reduced grain yields of a subsequent crop, regardless of which species of cereal was used in the mixture (Table 2). Clearly, if the use of crop mixtures is to be encouraged, there is an urgent need to discover the causes of yield decline in continuous cereal systems, which can reduce yields to one third in 3 years (Keatinge et al, 1984).

Table 2. Effect of proportion of legume in cereal/legume forage mixtures on subsequent grain yields of barley (kg/ha): yields are means of 2 years.

Legume/cereal ratio	Vetch/cereal	Pea/cereal
0:100	986	1069
33:66	1209	1196
50:50	1317	1299
66:33	1340	1370
100:0	1536	1800

Source: A.E. Osman (personal communication).

High harvesting costs could be avoided if the forages were grazed instead of cut for hay or straw. Such an approach has been adopted by Thomson et al (1985) who found that growing forages (*V. sativa* and *L. sativus*) was almost as profitable as growing barley, the accepted enterprise in the villages where they worked. Their results, obtained where annual rainfall is only 280 mm, extend the use of forages to much drier areas than is currently possible. Dry-matter yields were only 2 t/ha, far below those possible in wetter areas, and they used seeding rates of 150 kg/ha, a major contributor to costs. However sufficient seed was produced on only 20% of the sown area for the farmer to perpetuate the system. As a result of their work there is an increasing demand for the seed in the villages concerned.

Grazing forage crops provides feed in spring, the season of least need. It may be more useful to graze mature crops in summer, a practice that has received some attention in Australia. Allden and Geytenbeek (1980) examined nine legumes including chickpeas (*Cicer arietinum*) and faba beans (*V. faba*) and found that lambs grazing mature crops gained up to 160 g/day, although this rate fell markedly after rain, which reduced digestibility of the forage from 55% to less than 40%. Their results indicated that if *V. sativa* were to be used in this way genotypes with non-shattering pods would be most useful. Genes for this character have been identified at ICARDA and will be incorporated into agronomically suitable varieties. It is worth noting that faba beans produced the greatest liveweight gains, and chickpeas, field peas and barley the least.

A recent discovery concerns the palatability of field peas. This crop has attracted a great deal of attention because of its high herbage yields. However, in mixtures with barley, sheep prefer barley, whereas in barley-vetch mixtures vetch is preferred. It now seems that hay made from peas is also unpalatable, voluntary intake often being less than half that of vetch (Table 3). This result demonstrates, if nothing else, the dangers of ignoring the consumers, in this case sheep, in agricultural research.

Whatever the problems of growing forage crops, it seems likely that they will be resolved by innovative farmers and scientists. The resulting systems will increase livestock production without detrimental effect on cereal production. The possible beneficial effects on cereals will be discussed later.

INTEGRATION THROUGH REPLACEMENT OF FALLOWS WITH SELF-REGENERATING ANNUAL PASTURES

Annual pastures comprise legumes which, through the possession of seed dormancy, volunteer in the pasture phase of cereal/pasture rotations and are grazed directly, the term 'ley' meaning land under natural grass, referring to the

Table 3. Intake of *in vivo* digestible dry matter (g/kg $MW^{0.075}$) of four forage crops fed at various growth stages, and weight gain of Awassi sheep (g per day) receiving the four forages for 28 days.

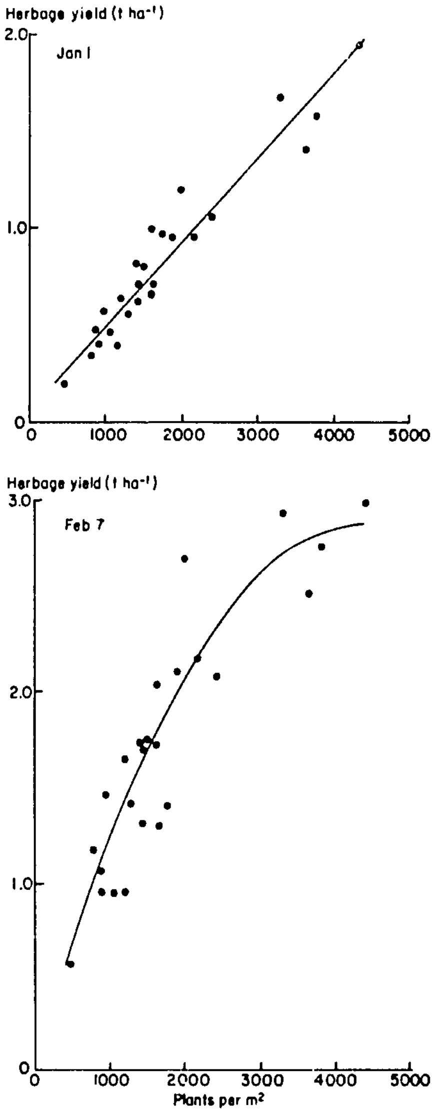
	Intake (g/kg $MW^{0.075}$)	Weight gain (g/day)
(a) Fed fresh		
Barley	66.8	308
Vetch	80.1	355
Peas	16.0	-236
Lathyrus	80.9	282
(b) Fed as hay		
Barley	57.8	322
Vetch	71.8	259
Peas	26.5	-72
Lathyrus	62.5	205
(c) Fed as straw		
Barley	15.6	-259
Vetch	37.9	-30
Peas[1]	24.4	-158
Lathyrus	34.1	13

1. Of four sheep, two refused to eat pea straw. The figures represent intake and weight gain of the other two sheep.

Source: E. F. Thomson, N. Nersoyan and A. Termanini (personal communication).

ability of pastures to naturally reseed. In ley farming the main period of pasture growth is spring, when plant growth rates of up to 150 kg/ha per day are possible. Excess spring growth is eaten by animals in summer and, even though the plant material is dry, it is possible for sheep to maintain or even increase their weight on pasture and cereal residues. Late autumn and winter are the critical periods, during which pasture growth rate depends on plant numbers (Figure 2), but even in the cold Aleppo winters pasture growth rate is up to 30 kg/ha per day.

Figure 2. *The relationship between herbage yield of regenerating pastures and plant density in (a) early winter, and (b) late winter.*



Ley farming originated in the Mediterranean region of southern Australia using two widely distributed plant groups: subterranean clover (*Trifolium subterraneum*) and annual medics (including *M. truncatula*). It was developed at a time when meat and wool prices were high, cereal yields were falling, farmers were worried about soil erosion, and naturalised pastures were responding to superphosphate applied to crops. New tillage machinery, designed to cultivate the usually shallow Australian soils, also encouraged pastures by burying seeds at depths from which small seedlings could emerge. Cereal yields in the region have increased by 70% and livestock numbers by up to 400% since the ley-farming system was introduced (Cocks et al, 1980; Puckridge and French, 1983).

Carter (1978) estimated that approximately 30 million ha of fallow land in North Africa and West Asia are suitable for ley farming. If 70% of this land were sown to pastures he estimated that approximately 80 million tonnes of herbage would become available, enough to feed 100 million ewes. He went on to calculate that 1.4 million tonnes of N would be added to the soil per year, an amount 65% greater than is currently applied as fertilizer in Algeria, Tunisia, Libya, Jordan, Syria, Turkey, Iran and Afghanistan combined.

Some of Carter's assumptions have been tested near Aleppo. We have recorded herbage yields of up to 9 t/ha where Carter assumed only 4 t/ha. Even on first-year pasture, five sheep can be grazed per hectare and regenerating pasture can carry more: Carter's assumption was three sheep per hectare. Up to 150 kg N/ha has been fixed by medics, more than enough to add to the soil the 60 kg N/ha assumed by Carter and based on long-term Australian experience (see ICARDA, 1985). There is little doubt that this is a very potent method for integrating cereal and livestock production with enormous potential benefit to farmers in the Mediterranean region.

If there are so many benefits, why is it that farmers are not practising ley farming? Most of the circumstances are favourable: livestock prices are high, native legumes are widespread, cereal yields are either declining or becoming dependent on fertilizer N, and soil erosion is a widespread problem. In the 20 years since 1965 numerous attempts have been made to introduce the system, with little success. I believe that there are three important reasons for the system not being adopted: lack of adapted pasture cultivars, lack of seed and an inadequate understanding of the nature of technology transfer. In particular localities there are other reasons, e.g deep ploughing and the lack of adapted rhizobia, but I will not discuss these further.

The first reason is lack of adapted cultivars, and I will refer to annual medics since, on alkaline soils, they are preferred to subterranean clover. In Australia the two most widely-grown species are *M. truncatula* and *M. littoralis,* both of which are commonly found near the sea: Indeed the distribution of *M. littoralis*, as its name implies, is restricted to the coast. That they are successful in southern Australia is not surprising since its climate is similar to the littoral zone of the Mediterranean Sea, especially Morocco, Tunisia and Libya. In general, when reintroduced to North Africa and West Asia they succeeded where they were native and failed elsewhere, especially in Iraq (Radwan et al, 1978), Syria, Jordan and the high plateau of Algeria (Saunders, 1976).

It has long been recognised that indigenous medic species are widespread and represent a valuable resource (Chatterton and Chatterton, 1984). Many collections have been made, e.g. Gintzburger and Blesing (1979) in Libya and Rumbaugh and Graves (1981) in Morocco, but the identification of new cultivars has been slow. This is due partly to the difficulty of selecting for adaptation to ley farming in a region where ley farming is not practised. Nevertheless it now seems clear that in north Syria, *M. rigidula* is adapted to both the environment of zone 2 and the system (Abd El Moneim and Cocks, unpublished data). Its adaptation to cold is illustrated in Table 4, where its survival after prolonged frost was 95% compared with about 15% by Australian cultivars of *M. truncatula, M. polymorpha* and *M. scutellata*. Similarly

Table 4. Number of plants which germinated and their survival after severe frosts of seven medic genotypes including four Australian cultivars.

Species and genotype	Number of seedlings before frost (per m^2)	Survival (%)
M. scutellata cv. Robinson	232	5
M. truncatula cv. Cyprus	536	7
M. truncatula cv. Jemalong	432	14
M. polymorpha cv. Circle Valley	856	21
M. rotata sel. 2123	1144	90
M. rigidula sel. 716	816	95
M. rigidula sel. 1919	864	98

Source: P.S. Cocks (unpublished data).

M. noeana, endemic to northern Iraq and Turkey, *M. rotata*, growing on volcanic soils in southern Syria and Jordan, and *M. aculeata*, widespread in the mountains of Algeria, are potentially valuable species. Clearly, the principle must be to choose new cultivars from the native medic population.

Lack of local seed production is a major constraint, especially in areas where the Australian cultivars fail. A commericial seed industry requires special harvesting and cleaning machinery, technicians (or farmers) capable of correct preparation of land and control of specific weeds, and appropriate certification and inspection procedures. However, no seed industry will develop unless there is demand for the seed, and demand itself is reduced by lack of seed. It may be possible to break this nexus by using contractors outside the region to produce seed of adapted cultivars to stimulate short-term demand, and instigate a research and training programme in seed production within the region to meet long-term demand. For this to be implemented, local authorities need to be convinced of the long-term economic benefits of ley farming.

Introduction of ley farming has suffered from an inadequate understanding of the process of technology transfer both by expatriate experts and by local authorities. For example, in projects aimed at introducing ley farming, heavy, expensive machinery is often used because there is a commitment to develop large areas, more than 20 000 ha in one instance. In most cases sheep are managed using fences, and sometimes such clearly unsuitable practices as castration of male lambs have been advocated. There is also a belief, to some extent nurtured by expatriates, that ley farming will transform agriculture in very few years, and the disappointment that follows when it fails to do so often leads to disillusion. None of this is necessarily the fault of any particular group but indicates an attitude of mind towards technology transfer which minimises problems.

Farming practices are very diverse within the region, varying from small owner-operated farms to large state-managed farms. Before implementing new technology a knowledge of farming systems is needed, especially an understanding of resources available to farmers, their skills and knowledge, and why they do what they do (e.g. Springborg, 1985). There is also a need to understand the significance of small environmental differences: very small differences in soils, climate and weed flora, for example, can have large effects on the success of new technologies. It may be best to simply introduce a concept, in this case rotation of cereals with pastures, then, by restricting the use of resources to those already available, encourage farmers to build their own systems around the concept. Farmers would need continued access to advisers and scientists to help them resolve problems as they arise.

In this context an important mistake made by many proponents of ley farming is to emphasise its impact on cereal production (e.g. Doolette, 1980) rather than livestock production. The result has been lack of integration, even to the extent of neglecting livestock altogether. This has implications on other components of the system: For example, many of the difficulties associated with weeds are symptoms of poor grazing management. On the other hand, what Australians mean by good grazing management -- continuous grazing at a rate which does not deplete seed reserves -- may not be possible if farmers do not own livestock.

Nevertheless, ICARDA remains confident of the potential of ley farming. At a village near Aleppo a farmer has developed a version of ley farming with considerable success. Using his 5 ha of native medic as a focus, ICARDA and the Ministry of Agriculture are providing seed of local medics to an increasing number of his neighbours, whose interest was aroused by the original field. Inputs are limited to seed and rhizobia, the project otherwise using only local resources, although, because the project is regarded as experimental, the farmers receive compensation for use of their land in the first year. It is too early to be confident of success, but widespread interest has been aroused, both within and beyond the village.

THE IMPACT OF PASTURE AND FORAGE CROPS ON CEREAL YIELDS

No discussion of the role of pasture and forage legumes can ignore their ability to fix atmospheric N. Both groups of legumes are able to fix large amounts of N, Keatinge et al (1984) recording that forage peas fixed up to 170 kg N/ha, while *M. noeana* and *M. rigidula* fixed 140 and 150 kg N/ha, respectively (ICARDA, 1985). The important point is how much of this remains for the use of the following crop. If, in the case of forages, the herbage is cut and removed, as is the normal practice, the answer must equal the amount present in roots, likely to be no more than 10-15% of that in the tops. The effect of this amount of N on subsequent grain yield is likely to be low, especially in dry areas where total N fixation is much less than that quoted above. Reasons for the beneficial effects of forage crops on cereal production (if any) must be sought elsewhere.

In ley farming, pastures are grazed *in situ*, so the amount of N removed will be less than in forage systems.

However, because of the long-term nature of changes in soil fertility, detailed analysis of their effect on cereal yield is not yet possible. In Australia, where there is a longer experience of ley farming, the rate of N accretion under subterranean clover is about 50 kg N/ha per year for periods of up to 40 years (Russell, 1960; Donald and Williams, 1954). In rotation with cereals, Carter (1978) states that 70 kg N/ha per year is a reasonable estimate, and Puckridge and French (1983) quote several authors who measured rates of increase varying from 30 to 150 kg N/ha per year.

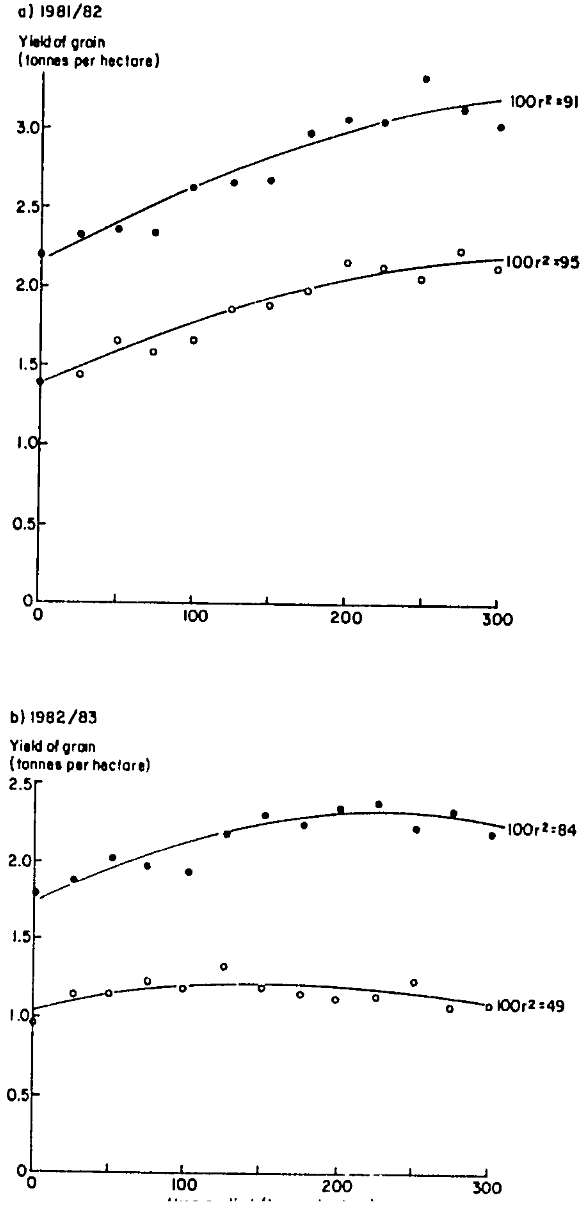
In the shorter term, pastures and forages produce similar effects to other breaks between cereals, including fallows. In northern Iraq the yield of wheat after medic was 1 t/ha higher than that of wheat after wheat (Figure 3) and approximately equal to wheat after fallow (P.S. Cocks, unpublished data). Since the response of both crops to N was the same the difference in yield was attributed to control of cereal root diseases. This conclusion is supported by extensive Australian work: Rovira (1980) reported that both medics and peas in rotations with wheat increased wheat yields by 100% compared with wheat after either wheat or oats, by controlling *Gaeumannomyces graminis*, a fungus that attacks cereal roots.

CONCLUSIONS

Can these models of integrated livestock/cereal farming be extended to other climatic types? Since this paper is being presented in Addis Ababa I would like to briefly discuss this question in relation to the highlands of Ethiopia.

Ley farming depends on the ability of Mediterranean annual legumes to produce large amounts of dormant seeds which become viable over several years. Presumably, if species with similar characteristics were present, ley farming could be developed in other environments. I would like to suggest that the annual species of *Trifolium* present in the highlands of east Africa are likely to possess these seed characters.

Figure 3. *The effect of urea application in (a) 1981/2 and (b) 1982/3 on the yield of wheat sown after medic and wheat at Erbil in northern Iraq.*



One species of medic (*M. polymorpha*) and 28 species of *Trifolium* are present in Ethiopia, many of the latter being endemic or present elsewhere only in neighbouring countries. Of the 28 species of *Trifolium*, 19 are annuals falling into two sections of the genus, Lotoidea and Mistyllus (Zohary and Heller, 1984). They grow widely as volunteers on fallows and occur as weeds in crops throughout the temperate highlands, a distribution and ecology which strongly suggests that they possess the characteristics necessary to succeed in ley farming. They respond strongly to phosphorus, by up to 600% (Haque and Jutzi, 1984).

Recent work on the value of vetches is also of interest (Kenno and Gebrehiwot, 1983). Dry-matter yields more than 6 t/ha were obtained from *V. atropurpurea, V. villosa*, and *V. sativa* at five highland locations. Kenno and Gebrehiwot believe that vetches will fit well into cereal/fallow rotations by reducing weed populations in subsequent crops and improving soil fertility. This has still to be proven, but the preliminary work of these and earlier authors (e.g. Haile, 1977) should encourage the development of integrated systems in Ethiopia.

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THE ROLE AND POTENTIAL OF FORAGE LEGUMES IN ALLEY CROPPING, LIVE MULCH AND ROTATION SYSTEMS IN HUMID AND SUBHUMID TROPICAL AFRICA

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ABSTRACT

Fragile, low activity clay soils, which are prone to erosion and are characterised by inherently low fertility, are common in humid and subhumid tropical Africa. On these soils, forage legumes play an important role in developing sustainable and low input crop production systems. Woody and herbaceous species such as *Leucaena leucocephala, Gliricidia sepium, Flemingia congesta* and *Sesbania rostrata* have shown good potential for inclusion in alley cropping systems. *Mucuna pruriens* var *utilis* is one of the most promising sources of *in situ* mulch in small- and large-scale crop production. Live mulches of *Psophocarpus palustris* and *Centrosema pubescens* smother weeds effectively and have been shown to sustain high maize yields with little fertilizer N input. Despite the encouraging results obtained with forage legumes on less acid soils, further research is needed to select species that can be included in low-input crop production systems on strongly acid soils.

INTRODUCTION

Although a wide range of soil types are found in the humid and subhumid regions of tropical Africa, highly weathered and low activity clay (LAC) soils (Ultisols, Oxisols and

Alfisols) are the most important groups used for upland crop production (Kang and Juo 1981). According to Dudal (1980), Ultisols make up 46.7% and Alfisols 12.5% of the land area in humid tropical Africa, while in the subhumid zone Ultisols and Oxisols comprise 25.6% and Alfisols 27.4% of the land area. Some of the major management problems with using these LAC soils for food crop production in the humid and subhumid regions of tropical Africa were reviewed by Hartmans (1981) and Kang and Juo (1981).

Ultisols and Oxisols are strongly acid and leached soils, occuring mostly in areas with perudic and udic moisture regimes. These soils are characterised by low cation exchange capacity (CEC), very low inherent fertility, multiple nutrient (N, P, K, Ca, Mg, Zn) deficiencies and nutrient imbalances. Toxic levels of Al or Mn or both are among the main chemical constraints to growing crops on these strongly acid soils. Alfisols, which have high base saturation and are less acid, are characterised by inherently low nutrient (N, P, K, S and Zn) status and low structural stability. They are therefore prone to erosion and compaction. Maintaining soil fertility and controlling soil erosion and compaction are thus major management problems in using these soils for crop production.

The traditional agriculture that is widely practised on the LAC soils is changing due to rapid increases both in human population and in the rate of urbanisation. These changes have resulted in the shortening of fallow periods, which are needed to restore and maintain soil productivity and to control weeds. Consequently, crop yields have declined in tropical Africa despite the introduction of improved cultivars. There is therefore a need to identify soil and crop management practices that can maintain soil fertility under more intensive land use. In recent years, interest has increased in the inclusion of herbaceous and woody forage legumes in crop production systems as sources of mulch, green manure and supplementary browse, to develop sustainable and low-input production systems (Brewbaker et al, 1982; Sumberg 1984; Kang and Duguma, 1985). The role of forage legumes in alley cropping, live mulch and *in situ* mulch systems will be discussed in this paper.

ALLEY CROPPING

Concept

In the humid and subhumid tropics, tree crop production, whether in plantations, on smallholdings or in compound farming has generally been most successful on LAC soils, as tree crops are ecologically suited to the environment and cause little or no damage to soil. Traditional farmers retain certain trees and shrubs in their crop production systems to restore soil fertility exhausted by cropping (Moorman and Greenland, 1980; Getahun et al, 1982). In efforts to replace or improve the traditional bush-fallow cultivation, investigations have been carried out on alley cropping, an agroforestry system in which arable crops are grown between rows of woody shrub or tree fallows (Kang et al, 1981; Wilson and Kang, 1981). The shrubs or trees are pruned periodically during the cropping season to prevent shading and to provide green manure for the companion food crop. Thus, the trees and shrubs grown in the hedgerows recycle nutrients and provide green manure, firewood and staking material, as is observed in the bush-fallow system. Alley cropping has the advantage over the traditional system of combining the cropping and fallow phases.

Forage legume species for alley cropping

Kang et al (1984) reviewed the important characterstics of trees and shrubs suitable for alley cropping. Legumes that meet most of the required characteristics for the humid and subhumid tropics include species of the genera *Albizia*, *Calliandra*, *Cassia*, *Flemingia*, *Gliricidia*, *Inga*, *Leucaena*, and *Sesbania*. Information about some of these fast-growing, nitrogen-fixing trees has been assembled by the National Academy of Sciences (NAS, 1980; 1983).

Among the *Albizia* species, *A. lebbek* is the most commonly grown; it can be pruned continuously and provides green material even in the dry season (Whyte el al, 1953). Many *Cassia* species are unpalatable and toxic, but some, e.g. *C. siamea*, are used for fodder in some tropical countries. *C. siamea* is commonly used as hedges in Nigeria and Zaire, and has also been recommended as a shade tree and for soil improvement in Rwanda (Behmel and Neumann, 1982). Yamoah (1985) observed that *C. siamea* suppressed weed growth and increase maize yields more than *Gliricidia sepium* and *Flemingia congesta* in alley cropping with maize on an Alfisol.

Sesbania species are herbaceous shrubs or small trees, used mainly for green manure. *Sesbania grandiflora, S. sesban* (Skermann, 1977), *S. aculeata* (syn. *S. cannabina* or *S. bispinosa*) and, in Mali, *S. rostrata* (T. Traora, personal communication), are also used as fodder. They have shallow roots and may compete for nutrients and moisture when grown with food crops. *Sesbania rostrata* is an annual shrub that grows in hydromorphic soils in the Sahel region of West Africa (Berhaut, 1976). It is unique in its profuse stem nodulation. Its beneficial contribution as green manure in rotation with rice grown in microplots in Senegal has been reported by Rinaudo et al (1983). It is also a potential N source for alley cropping with hydromorphic rice (Mulongoy, 1985). Tests done at IITA show that two prunings of *S. rostrata* planted at 10 cm x 200 cm spacing yielded 3 t DM/ha, which can contribute 70 kg N/ha during the rice cropping season. *Sesbania grandiflora* has also been tested in alley cropping at IITA but with little success. This species is severely damaged by insects in the area and cannot stand repeated pruning.

Leucaena leucocephala and *Gliricidia sepium* have been widely tested in alley-cropping systems, and both species are suitable for alley cropping on the less acid Alfisols and associated soils. Their prunings can be used for mulch, green manure and supplementary high quality browse for small ruminants, particularly during the dry season (Sumberg, 1984). On acid soils (pH <5.0), however, both species grow poorly and require liming and phosphate fertilization (Duguma, 1982). There is therefore a need to breed and select woody forage legumes species that grow well with low inputs on acid soils.

Hutton (1982) reported several promising interspecies crosses of leucaena for acid soils. Recent observations in eastern Nigeria showed that *Flemingia congesta* performs well in alley-cropping systems on acid soils (IITA, 1983). The junior author observed that in Yurimaguas in Peru, *Inga edulis* and *Erythrina* species have good potential for alley cropping on acid Ultisols. The fodder value of these species still needs to be determined.

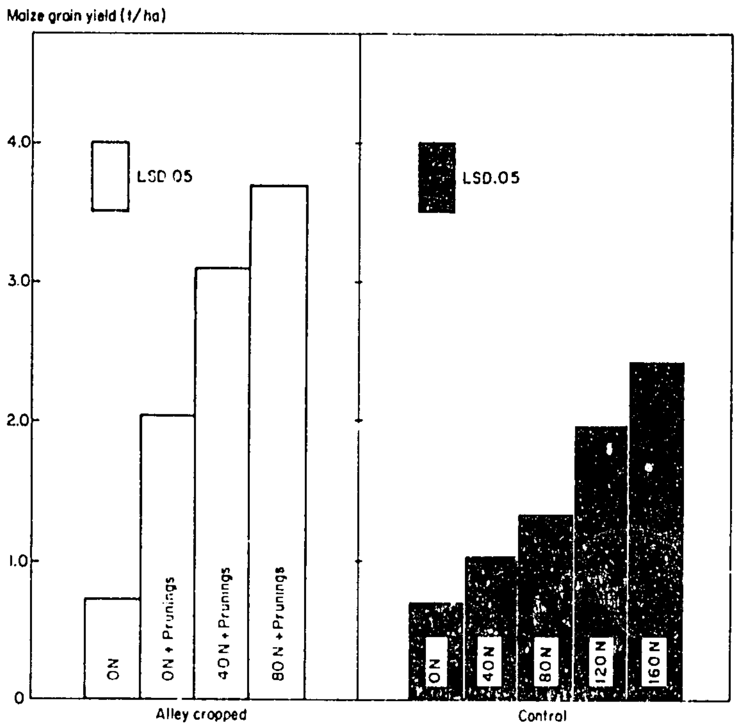
For rapid establishment, these woody leguminous forage species sometimes require inoculation with rhizobium. Leucaena nodulates effectively with only a narrow range of *Rhizobium* strains (Date and Halliday,1980). To ensure rapid establishment and N fixation, inoculation with the appropriate rhizobia is therefore recommended. Munns and Mosse (1980) also reported a significant effect of inoculation with mycorrhiza on the use of phosphate, growth, and nodulation of leucaena in pot trials using Alfisols from southern Nigeria. The importance of mycorrhizal inoculation under field conditions still needs to be assessed.

Nutrient contribution from leguminous trees and shrubs grown in hedgerows

Some promising results have been obtained in using *Leucaena leucocephala* and *Gliricidia sepium* in alley cropping with various food crops on the less acid Alfisols (Kang et al, 1985). Observations in southern Nigeria indicate that five annual prunings of leucaena and gliricidia grown in hedgerows spaced 4 m apart yielded over 140 and 230 kg N/ha per year, respectively (Kang and Duguma, 1985). Despite the high N yield, supplemental N application was still required to obtain high maize yields (Kang et al, 1981). This was due in part to low efficiency of N in the prunings, as was also reported by Guevarra (1976). It is estimated that prunings from leucaena hedgerows spaced 4 m apart contribute 40 to 60 kg N/ha to the associated maize crop. Besides N, leucaena also recycles large quantities of other nutrients. In one trial conducted on an Alfisol in southern Nigeria, nutrient yields in leucaena prunings amounted to 10.6 kg P, 153.4 kg K, 73.7 kg Ca and 15.9 kg Mg/ha.

The long-term cumulative effect illustrated in Figure 1 is very important in alley-cropping systems. Higher maize yields in the long-term alley-cropping plot as compared to the control plot cannot be attributed solely to the N contribution of the prunings but reflect a general improvement in soil conditions.

Figure 1. *Grain yield of maize variety TZPB grown on Psammentic ustorthent as affected by nitrogen application and 6 years of alley cropping with Leucaena leucocephala (Kang and Duguma, 1985).*



LIVE AND IN SITU MULCH SYSTEMS

Concept

Most tropical soils are inherently low in nutrients and are prone to erosion, especially after deforestation and subsequent cultivation with conventional mechanical tillage (Hartmans et al, 1982). Also, traditional farmers in the tropics spend 40 to 60% of their labour time on weeding. Hand or mechanical weeding causes structural deterioration of surface soil and exposes the soil to erosion. Chemical weed control is usually too expensive for these small farmers.

Although mulch farming has proven to be effective in controlling soil erosion and in improving soil properties, resource-poor farmers have always been reluctant to adopt conventional mulching, because of the large amount of labour needed to gather, transport and apply the mulch. The search for inexpensive and more attractive mulching methods has led to the development of *in situ* and live mulch.

The term *in situ mulch* refers to the residues of dead or chemically killed cover crops which are used on the same land on which they were grown (Wilson, 1978). The land is usually left for at least one cropping season under the cover crop to produce the mulch (Hartmans et al, 1982).

The live-mulch system is a crop production technique in which food crops are planted directly in a low-growing cover crop with minimum soil disturbance (Akobundu, 1980). This practice is based on the concept of using cover crops in tree plantations. Its main advantage is that it smothers weeds, and it can play an important role in soil conservation and maintenance of soil fertility.

Forage legumes for in situ and live mulches

Leguminous cover crops are often used for *in situ* and live mulches because of their ability to fix atmospheric N when they are effectively nodulated by rhizobia. The high forage value of these legumes may make them more attractive to farmers as part of their livestock and crop production system (Botton, 1958).

The choice of legumes for live and *in situ* mulch systems is based on several characteristics. They should be easy to establish, produce sufficient biomass in a short time with little or no fertilizer inputs and nodulate effectively with indigenous rhizobia. Species that grow rapidly and vigorously will be able to smother weeds effectively. They should not increase pest and disease incidence and should be easy to eradicate by inexpensive means. For the live-mulch system, they should be perennial and should not compete with the associated crops.

Various forage legumes possess a number of these attributes. A few species were tested for *in situ* and live mulch on Alfisols at the IITA main station in Ibadan (Okigbo and Lal, 1977; Lal et al, 1979; Akobundu, 1980; Wilson et al, 1982; Akobundu and Okigbo, 1984). Results of live-mulch trials in which maize, cowpea and rice were grown with *Arachis prostrata, Indigofera spicata, Centrosema pubescens* and *Psophocarpus palustris*, showed that growing maize in live mulches of the last two legumes was the most promising system. The climbing habit of *P. palustris* and *C. pubescens* can be controlled by spraying with the growth hormone, CGA 47283, at 2 kg a.i./ha (Akobundu, 1980). *Indigofera spicata, Pueraria phaseoloides* (Kudzu), *Stylosanthes guianensis* and *Mucuna pruriens* var *utilis* (syn. *Stizolobium deeringianum* or velvet bean) have been found to be good sources of dead mulch for minimum-tillage systems. *Pueraria* is adapted to low altitudes and was widely tested as a cover crop and fodder plant before the 1960s in Central Africa and Liberia. *Pueraria* interplanted in rice fields in Sierra Leone suppressed weeds, increased rice yields and provided fodder after the rice had been harvested (Whyte et al, 1953). *Mucuna* has been studied widely in Nigeria, Zaire and Zimbabwe for green manure and temporary pastures (Falkner, 1934; Whyte et al, 1953; 1979).

There are a number of other forage legumes that may have potential as live *in situ* mulch, such as *Centrosema plumieri*, *Desmodium ascendens*, *D. canum*, *D. scopirus*, *Calopogonium mucunoides* and *Mimosa pudica*. The characteristics of these species have been described by Whyte et al (1953), Botton (1958), Skerman (1977) and Burt et al (1983).

Adapted cover crops usually nodulate freely in tropical soils. Some of them, such as *Centrosema*, *Stylosanthes* and *Desmodium* species require inoculation with specific rhizobia for proper nodulation and N fixation (Skerman 1977; Date and Halliday, 1980). In acid soils, legumes generally nodulate less, due to poor survival of the rhizobia and failure of tolerant strains, even if they are abundant, to infect the root hair. The acidity can be corrected with liming if lime is available. Legumes also have a high P requirement for nodule development and optimum plant growth. Plants growing in association with mycorrhiza use native and added P more effectively than plants without mycorrhizae. Many of the tropical legumes are dependent on the presence of mycorrhizae for P uptake (Mosse, 1981). Nodulation and symbiotic nitrogen fixation of some species are even contingent on mycorrhizal infection. Crush (1974) showed that *Centrosema* sp. seedlings nodulated only when infected with mycorrhizae or when P was applied. *Stylosanthes* grown in several tropical soils failed to grow adequately or to nodulate without mycorrhizal infection even when P was applied (Mosse et al, 1976).

Soil restorative and protective value of in situ and live mulches

The soil restorative and protective value of organic mulches is well known (Lan, 1984). Scientists working in the tropics showed early interest in using leguminous cover crops for soil restoration (Faulkner, 1934). Results of a series of continuous-cropping experiments using leguminous cover crops, particularly *Mucuna pruriens* var *utilis*, conducted in Ibadan, Nigeria, from 1922 to 1951, showed that mucuna improved soil properties but that its effect was not long lasting. Studies by Lal et al (1978) and Wilson et al (1982) also showed improvement in soil physio-chemical properties and biological activities, as measured by earthworm cast production, under *Stylosanthes guianensis*, *Centrosema pubescens*, *Pueraria phaseoloides* and *Mucuna pruriens* grown for only a short period, as compared with natural fallow. The cover crop improved soil bulk density and soil moisture retention and gave better protection against erosion. We also observed higher microbial biomass under *Psophocarpus palustris* live mulch than in bare plots (Table 1).

Table 1. Some chemical and microbiological characteristics of the soils (0-10 cm) under *P. palustris* live mulch on land that had been continuously cropped to maize for five seasons.

Soil characteristics	Live mulch		Bare soil
	Casts	Soil	
pH	6.1	5.5	5.6
Organic C, %	3.36	1.80	1.73
Total nitrogen, %	0.51	0.21	0.18
Bray-1 P, ppm	30.5	5.3	9.6
Ca^{2+}, meq/100g	12.7	2.5	1.4
Mg^{2+}, meq/100g	3.2	0.4	0.2
Mn^{2+}, meq/100g	0.08	0.04	0.06
K^+, meq/100g	1.0	0.2	0.1
Na^+, meq/100g	0.24	0.19	0.16
CEC, meq/100g	17.3	3.54	2.2
Microbial biomass C, mg/100g	44.7	19.4	17.6

Source: K Mulongoy (unpublished data).

Nitrogen fixation and nitrogen contribution

Forage legumes can fix atmospheric N when they are effectively nodulated, and thus can contribute to the N economy of cropping systems. This potential is currently still underutilised, particularly in the tropics. Little information is available on N fixation by forage legumes in the field in tropical Africa. On low-N soils, the amount of N fixed is closely correlated with legume dry-matter production (Skerman, 1977; Vallis et al, 1983). Annual dry-matter yields of forage legumes that are useful in live and *in situ* mulch systems range between 1500 and 7500 kg/ha in Africa (Skerman, 1977; Mulongony and Akobundu, 1985), with N yields ranging from 30 to 300 kg/na per year.

A number of reports have indicated that forage legumes increase the organic matter and N contents of the soil (Tables 1 and 2). Most of these studies dealt with legume-grass mixtures. Observations by Lal et al (1979) and Wilson et al (1982) showed small increases in soil N content ranging from 0.01 to 0.06% over a 2-year period.

Table 2. Some physio-chemical characteristics of the soils (0-10 cm) after 2 years of cover crops.

Cover crop	Bulk density (g/cm^3)	Organic C(%)	Total N(%)	Bray-1 P (ppm)	CEC (meq/100 g
Centrosema pubescens	1.33	1.53	0.18	33	10.0
Mucuna utilis	1.33	1.57	0.21	35	10.5
Psophocarpus palustris	1.14	1.57	0.20	37	10.9
Pueraria phaseolodids	1.32	1.50	0.17	24	7.7
Stylosanthes gracilis	1.33	1.63	0.21	38	8.8
Control (bare soil)	1.42	1.37	0.17	19	8.4
LSD (0.05)	0.04	0.23	0.03	22	3.5

Source: Lal et al (1979).

Mulongoy and Akobundu (1985) studied nitrogen uptake by maize grown in live mulches of *Psophocarpus palustris, Centrosema pubescens* and *Arachis repens*. In newly established live-mulch plots, the cover crops and maize competed for N. Poor nodulation and N fixation, aggravated by application of a growth retardant (CGA 47283) used to reduce the climbing tendency of the live mulch, corroborated this observation. Positive N contributions (46, 48 and 2 kg N/ha for the three legumes respectively) were obtained in the fifth cropping season i.e. 2.5 years after establishment of the live mulches and continuous cropping with maize. The positive N contribution may have been due partly to the accumulation of organic matter under the mulch.

Effects on nematodes

Plant parasitic mematodes are among the major soil-borne plant pests that are suppressed effectively by the bush-fallow system (Wilson and Caveness, 1980). Forage legumes show a range of susceptibility to species of nematodes. Some of them are not only resistant but create conditions adverse to the pest and, therefore, could control populations of parasitic nematodes when they are used in live or *in situ* mulch systems. For instance, the population of *Meloidogyne incognita*, which is not considered as a serious maize pest, increased under *Psophocarpus palustris* but the number of *Helicotylenchus pseudorobustus*, the spiral nematode which is harmful to maize, decreased (Hartmans et al, 1982). Such beneficial interactions between the food crop and the legume justify more research on the influence of *in situ* and live mulches on certain plant pests.

Effects on weeds

Forage legumes, particularly prostrate types such as *Centrosema pubescens, Pueraria phaseoloides* and *Mucuna pruriens*, compete with and smother weeds successfully when well established. Research by INEAC in Zaire also has indicated the advantage of using leguminous cover crops such as *Pueraria javanica, Stylosanthes guianensis* and *Calopogonium mucunoides* to eradicate *Imperata cylindrica* in the savannah region (Jurion and Heneray, 1969). At IITA main station, Akobundu and Okigbo (1984) tested several ground-cover crops over a 2-year period to determine their effects on weed competition and maize yield. Maize was planted directly into already established cover crops. Weed infestation was heaviest in *Desmodium triflorum, Indigofera spicata* and in no-tillage control plots; was moderate in *Arachis repens* and maize-stover plots: and very low in *Centrosema pubescens* and *Psophocarpus palustris* plots. Good maize yields were obtained where weed competition was minimised by the legume cover crop. It is important to note that the thick mulch obtained with some cover crops such as *P. phaseoloides* can seriously reduce the maize stand, especially with mechanical planting. Martin and Touchton (1982) reported a similar effect on sorghum grown in a legume cover crop.

Effects on crop yield

The reason for using leguminous cover crops in rotation and intercropping systems is to obtain sustained and high crop yields with minimum N fertilizer input.

Earlier work with cover crops at Moor Plantation in Ibadan, Nigeria, from 1922 to 1951 (Faulkner, 1934; Vine 1953) showed that, though the cover crops have no long lasting effect, inclusion of *Mucuna pruriens* in the rotation system, supplemented with low fertilizer rates, could maintain adequate maize yields. Faulkner (1934) estimated that the increase in yield of a maize crop following a *Mucuna* crop was in the order of 700 to 900 kg grain/ha. Kannegieter (1966) also reported increases in crop yield in Ghana following a short-term fallow on which *Pueraria phaseoloides* was grown.

Agboola and Fayemi (1971) observed that intercropping maize with *M. pruriens* reduced maize yield but intercropping with *Calopogonium mucunoides* did not affect the maize yield. The same authors (Agboola and Fayemi, 1972) also showed that *C. mucunoides* intercropped with maize fixed 370 kg N/ha but did not benefit the early corn crop. However, it was of benefit as a green manure for the late cropping season.

Wilson (1978) reported increased yield and improved quality of tomatoes grown with an *in situ* mulch of *P. phaseoloides*. Lal et al (1978) also observed that, after 2 years, *in situ* mulches of *Centrosema pubescens, P. phaseoloides* and *Stylosanthes guianensis* increased the yields of cowpea, soya bean, maize and cassava. Among the leguminous cover crops evaluated on Alfisols and associated soils at IITA for *in situ* mulch, *M. pruriens* was the most promising for both large- and small-scale crop production. In areas with a pronounced dry season of longer than 2 months, the plant dies naturally, leaving 4 to 5 t of dry mulch/ha, suitable for no-till planting. To control volunteers, spraying with low doses of herbicides may be necessary.

As live mulch, *C. mucunoides* gave increases in maize yield equivalent to applying 55 kg fertilizer N/ha (Agboola, 1980). Akobundu (1980) also observed that after five seasons of continuous cropping, maize yields were higher from plots with a live mulch of *Psophocarpus palustris* and *Centrosema pubescens* than from bare plots under minimum or conventional tillage. Maize in the live-mulch plots showed little or no N response, whereas in the no-tillage system, maize responded to application of more than 60 kg N/ha. It thus appeared that leguminous live mulches contributed to the N needs of the maize crop. Although good results were obtained on Alfisols, Faulkner (1934) reported disappointing results on strongly acid Ultisols in southeastern Nigeria, mainly due to poor establishment of the cover crops.

CONCLUSIONS

Some research has been done into developing planted fallows which restore soil fertility sooner and are easier to manage than natural fallows. Paramount to this research is the development of stable, viable and environmentally sound low-input production systems on the fragile LAC soils. Research results thus far have shown that, on LAC soils in the humid and subhumid tropics, fallows have to be included in the farming systems in order to protect the soils and maintain satisfactory productivity. This can vary from one season fallow and use of a cover crop (such as *Mucuna*) to many years of managed fallows such as alley cropping and live-mulch systems that are economically productive (e.g. leucaena stakes, browse etc). Forage legumes can also reduce the need for N fertilizer in the production system and assist in nutrient recycling. Alley cropping and *in situ* mulch systems are ready for testing by farmers. More cooperative work, as is currently done between IITA and ILCA in alley farming research, also needs to be carried out on the use of some of these leguminous forage crops for animal production.

One important area that needs more research is the selection leguminous species for use on planted fallows and as forage that will perform well on acid soils with low chemical inputs.

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CONTRIBUTIONS OF FORAGE LEGUMES TO PASTURE PRODUCTION IN THE CARIBBEAN

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ABSTRACT

The Caribbean and Central American region is the centre of origin of many of the world's best known tropical forage legumes, yet they play only a minor role in pasture production in several areas in the region. The soils used for pasture production in the region are generally those that cannot support crop production. Over the last 15 years legume species have been systematically collected and evaluated in an attempt to find legumes that can be used to increase the forage quality from more marginal lands in the region. The best-adapted plants from these studies were assessed for their ability to sustain livestock production by introducing them into native pastures in grazing trials. The work was conducted in Belize, representative of wet areas of the Caribbean with infertile poorly drained soils, and in Antigua in a semi-humid to semi-arid climate on expanding clay soils of high pH. Legumes adapted to these marginal conditions have now been identified. For poorly drained acid soils, suitable species include *Codariocalyx gyroides*, *Desmodium ovalifolium*, *D. heterophyllum* and *Pueraria phaseloides*. On infertile, freely drained soils, *Calapogonium mucunoides*, *Desmodium ovalifolium* and, to a lesser extent, *C. gyroides* are quite promising. The browse plant, *Gliricidia sepium* is endemic in these areas. Applying small amounts of P fertilizer has also resulted in important changes in the floristic composition of pastures in these

areas, increasing the proportion of native legumes and better-quality grasses in the sward. In better environments on the smaller islands the range of adapted legumes is greater, including *Stylosanthes hamata* (Caribbean), *S. guianensis*, Siratro, *Teramnus labialis*, *Desmanthus virgatus*, *Centrosema* spp., *Clitoria ternatea* and *Glycine wightii*. The browse plant *Leucaena leucocephala* is endemic in these areas and is well adapted.

DEFINITION AND DESCRIPTION OF THE AREA

The development of a viable livestock industry in the Caribbean region is of great economic importance. The Commonwealth Caribbean, the region that this paper is mainly concerned with, imports over US$ 500 million worth of food stuffs, a large part of which is livestock products which could be produced locally.

The Caribbean region includes two relatively large mainland territories at the two extremities -- Guyana to the south on the South American coast and Belize to the north, geographically a part of Central America. The other territories are islands divided into groups known as the Windward Islands (Dominica, St. Lucia, St. Vincent and Grenada), the Leeward Islands (Antigua and Barbuda, Montserrat, St. Kitts/Nevis and Anguilla), the British Virgin Islands, Trinidad and Tobago, Barbados, Jamaica, the Cayman Islands, the Bahamas and Turks and Caicos Islands. The French islands of Martinique and Guadeloupe are part of the Windward group. The larger islands of Cuba, Hispaniola (Dominican Republic and Haiti) and Puerto Rico, part of the Greater Antilles, are the other territories of the Caribbean region.

The islands themselves can be further grouped into those that are essentially calcareous (Jamica, Barbados, Antigua and Barbuda Cayman Islands and the Bahamas) and those that are volcanic (Dominica, St. Vincent, St. Lucia, St. Kitts/Nevis, Montserrat, Grenada, and Tobago). Other islands and some of those listed above are calcareous, volcanic and metamorphic in origin. The mainland territories of Guyana and Belize have a more varied geologic history. The main part of Guyana is Pre-Cambrian but the coastal strip (approximately 1000 km^2), where the great majority of the population live, is very recent, consisting of a deposit of fine-grained Amazonian sediments. Most of Belize is calcareous in origin, being some of the oldest such deposits in the Caribbean region. Trinidad is essentially sedimentary, the sediments originating from South America and is not very old geologically.

The climate of the region is equally varied. The volcanic islands are usually oriented north/south with a central elevated volcanic region. This structure gives rise to a wet eastern and central part, where rainfall can exceed 7000 mm per annum, and a drier western part where the annual rainfall on average is about 1000 to 1200 mm. Jamaica has a wet northern and central part and a dry southern region. The calcareous islands are low lying and the rainfall received approximates that of the surrounding ocean, i.e. 875 mm to 1200mm. In these islands in particular, the reliability of the rainfall is poor. The island of Antigua, for example, suffers long droughts and periods of intense, heavy rainfall. In Trinidad, apart from the northern fringe of the island, there are no elevated land masses and due to the geographic location of the island, rainfall ranges from 1625 to 2500mm, decreasing from east to west across the island. In the islands the rainfall is essentially unimodal so that there are very wet and very dry periods. In Guyana the rainfall is bimodal with a range from 2000 to 2500 mm/annum. In Belize rainfall is unimodal with amounts ranging from 1750 to 3750 mm/annum.

Agriculture in the region is essentially crop based. Historically, sugar production has always been important. Other important crops are banana, rice, citrus, cacao and a range of food crops consisting of other cereals such as maize, and starchy root crops and vegetable crops. Livestock production has been secondary, except in Belize where beef production is the preferred farming enterprise. As far as animal production is concerned, there is a strong tradition that land which is completely unproductive for crops ought at least to be able to grow grass which should be capable of sustaining productive livestock. For these reasons, as stated earlier, livestock products comprise a large part of the food imports into the region. Australia and New Zealand are the main sources of meat and meat products, while European and North American countries are the main sources of dairy products.

THE LIVESTOCK INDUSTRY AND EARLY PASTURE RESEARCH

Livestock production, especially in the larger territories in the region, up to and including the Second World War was extensive in nature with animals grazing unimproved pastures, with average liveweight gains of 50 to 100 kg/ha per annum and carrying capacity ranging from several hectares per animal unit to about one hectare per animal unit. The poor animal performance largely reflected the poor quality grass component of natural pastures and the need for improved pasture composition and management techniques. The dominant grasses were relatively unpalatable, with high stem-to-leaf ratios and poor productivity under drought conditions.

After the Second World War, there was increasing awareness of the need to increase and improve animal production in the region. Bauxite mining in Jamaica became increasingly important during the 1950s, with mining companies such as ALCAN, ALCOA, Reynolds and Kaiser acquiring large tracts of land. The companies were required by law to keep such land in agricultural production until needed for mining and to re-form the mined-out land and to restore it to agricultural production after mining. They considered improved livestock production as one of the preferred agricultural enterprises into which they could expand, especially since very promising local breeds of cattle such as the Jamaica Hope, the Jamaica Black and Jamaica Red were appearing on the scene. At that time, the main forage production strategy in Europe and North America was to produce as much grass as possible by applying large amounts of nitrogen and to supplement this with concentrates in livestock diets. In a drive to improve livestock production in the Caribbean, this strategy was adopted and investigated in Jamaica by Nestel and Creek (1964; 1965), in Puerto Rico by Caracostas et al (1961) and Vasquez (1965) and in Trinidad by Adeniyi and Wilson (1960) and Wilson and Osbourn (1963). In some areas up to 800 kg N/ha per year were routinely applied with little attention to its effects on other soil properties such as pH.

Ahmad et al (1969) assessed the role of increasing N inputs in grass production, particularly with Pangola grass (*Digitaria decumbens*), a grass of high reputation which had been recently introduced into the region (Oakes, 1960; Nestel and Creek, 1962; Osbourn, 1969). These investigations showed that very large dry-matter yields could be produced by this grass with high N inputs and Pangola grass became sought after throughout the region. With time, poor adaptability of the grass became increasingly obvious. Nestel and Creek (1962) outlined a number of problems associated with this grass, including a number of insect pests and diseases which attacked it in the region, such as a virus disease identified in Suriname and Guyana (Dirven and van Hoof, 1960) which probably also spread to Trinidad and Tobago. In Trinidad, heavy infestation of sugar-cane frog-hopper (*Aenolamia* varia *Saccharina*) was also reported (Wilson and Osbourn, 1963). However, the major problem with the grass in the Caribbean was its intolerance of water-logging on the one hand and of drought conditions on the other and also its inability to persist and remain productive in problem soils, e.g. very acid or with poor physical properties, on which they were cultivated. As stated earlier, only soils that are not suitable for crop production are used for pasture in the Caribbean region. At the time that the lack of adaptibility of Pangola grass in the region was recognised the economic conditions in the region were also deteriorating and the price of N fertilizers was increasing. Thus, towards the end of the 1960s and in the early 1970s, improved pasture production lacked a relevant strategy and appropriate supporting research. Keoghan and Devers (1977) appropriately stated that pasture research in the Caribbean in the 1950s and 1960s can be described as characterised by Pangola grass syndrome, fertilizer-N spend-out, and expensive protein supplement addiction.

The Caribbean area and Central America are centres of origin of many of the legumes which are now considered important forage species, such as *Stylosanthes, Centrosema, Macroptilium, Calapogonium, Clitoria, Galactia, Zornia, Gliricidia, Prosopis* and *Leucaena*, and some *Teramnus* and *Desmodium* species. Each of these genera, however, are associated with particular ecological environments and hardly any are prolific on the infertile and unproductive soils that are being considered for pasture production. The flora of these areas consists of coarse, wiry grasses and sedges of extremely low palatability and nutritive value. In some areas of Guyana and neighbouring Venezuela, fire is used skilfully in management of these pastures to stimulate young growth with better palatability and feeding value, a technique which can be used to better advantage in the savannas of West Africa for instance.

In the late 1960s and early 1970s, it became necessary to face realities in pasture production in the Caribbean. With the limited land resources, the real challenge then, as indeed it is now, was to improve pasture productivity on the marginal soils that were considered unsuitable for crop production. Incorporating legumes in the native flora was seen as the obvious way of achieving this without adopting costly soil improvement schemes. In the late 1960s *ad hoc* attempts were made in Trinidad and in Belize in this direction by importing a few legumes from Australia, most of which were originally collected from this area but from better ecological habitats, and introducing them directly into pastures in these unfavourable environments. In Trinidad one of these introductions consisted of

Stylosanthes, Macroptilium, Centrosema, Calapogonium and *Pueraria* species oversown in established Pangola grass by tilling narrow strips and sowing seed of the selected legume on Piarco fine sand soil (Table 1). Plantings were also made in pure stand. Early growth was very good and the situation looked quite promising to the non-expert.

Fortuitously at this time (1969), an Australian collecting team comprising R. L. Burt and R. Isbell passed through Trinidad and they were taken to see this work in which the Department of Soil Science of the University of the West Indies was involved. On examination of the environment, they forecast that the particular legumes would very likely fail in the environment in which they were planted, as had other previous introductions of legumes unmatched to the particular environments in which they were tried. A more systematic approach was recommended in which legumes, both introduced and native, should be screened first for suitability to the specific environments.

CONTRIBUTIONS OF RECENT RESEARCH ON PASTURE IMPROVEMENT

Acting upon this advice, in 1970 successful negotiations were held with an international funding agent for financing a limited programme of assessing legumes for suitability to various marginal Caribbean environments. In the initial organisation of the programme of work it was decided to locate field trials in Belize (representative of the wet Caribbean), and in Antigua (representative of the dry Caribbean), where clay soils and soils of high pH are also characteristic (Hill, 1966). Microbiological studies were centred in Trinidad (Ahmed, 1978).

Antigua

The research centred on Antigua has helped to highlight the importance of indigenous forage legumes in pasture and livestock production. Among the Caribbean Islands, Antigua

Table 1. Properties of some Caribbean soils designated for pasture development.

Depth (cm)	Sand	Silt	Clay	OM	N	Base sat	CEC	Ca	Mg	K	pH (H_2O)	P ppm (Truog)
	Percent (%)						me/100g	Exchangable me/100 g				
					Fitches clay (Vertisol) Antigua							
0-15	18	14	71	3.8	0.23	100	63	60	25	1.49	8.0	17
15-30	18	14	71	3.2	0.22	100	60	70	15	0.85	8.0	12
30-60	13	11	79	nd	nd	100	54	72	15	0.33	7.9	nd
60-75	14	15	73	nd	nd	100	39	65	10	0.20	8.3	nd
					Hattieville Series (Ultisol) Belize							
0-14	16	79	5	1.02	0.06	60	3.0	1.1	0.6	0.1	5.9	3.9
14-20	30	26	44	0.49	0.04	48	6.2	1.3	1.4	0.1	4.9	2.4
20-30	20	23	47	0.39	0.03	55	8.5	2.7	1.7	0.1	5.0	2.5
30-60	15	39	46	0.17	0.02	80	11.3	6.7	1.8	0.1	5.1	4.2
60-120	15	38	47	0.12	0.02	92	14.8	11.1	2.0	0.1	5.3	4.9
					Ebini sandy loam (Typic Paleudult) Guyana							
0-13	75	9	17	1.92	nd	6	8.2	0.2	0.17	0.0	3.7	2
13-25	68	10	21	0.92	"	8	5.1	0.3	0.08	0.0	4.1	6
25-30	65	8	27	0.91	"	10	5.6	0.3	0.21	0.0	4.2	1
30-54	59	6	35	0.39	"	8	4.7	0.3	0.04	0.0	4.0	1
54-80	52	8	40	0.32	"	6	4.3	0.2	0.04	0.0	4.2	8
80-120	48	10	42	0.36	"	8	3.3	0.2	0.04	0.0	4.1	8
					Kairuni loamy sand (Arenic Paleudult) Moblissa, Guyana							
0-25	90	3	6	0.72	nd	2	6.4	0.1	0.04	0.0	4.2	nd
25-55	82	7	11	0.89	"	3	5.6	0.1	0.04	0.0	4.4	"
55-90	80	7	12	0.49	"	3	5.6	0.1	0.04	0.0	4.8	"
90-110	76	4	20	0.11	"	11	4.9	0.4	0.08	0.0	4.7	"
110-180	68	3	29	0.11	"	3	4.3	0.1	0.04	0.0	4.3	"
					Piarco Series (Ultisol) Trinidad							
0-12	73	9	18	1.0	0.09	20	2.0	0.0	0.5	0.05	4.3	Trace
12-37	63	11	20	0.2	0.03	42	1.9	0.0	0.5	0.05	4.4	0
37-95	53	9	40	-	-	16	3.7	0.0	0.2	0.06	4.3	0
95-135	37	9	52	-	-	14	5.7	0.0	0.2	0.07	4.6	0

has long been recognised as having good livestock production, both cattle and small ruminants. The main reason became apparent when the pasture improvement studies were started. It was found that several recognised pasture legumes were very prolific on the island and were prominent in the native flora. Due to fairly uniform climatic and soil conditions, the range of legumes was not great but the adapted species were quite dominant. *Stylosanthes hamata* and *S. guianensis* were important on shallow soils in hard-grazed locations and in the drier parts of the island. *Teramnus labialis* was also found to be common in pastures and to withstand drought and periodic over-grazing. The legume became increasingly prominent as the dry season advanced and in places was the dominant vegetation. Other ubiquitous small legumes were *Desmanthus virgatus, Rhyncosia minima, Macroptilium* spp, *Clitoria ternatea* and in wetter and protected areas, *Centrosema pubescens*. Browse legumes were also found to be prolific, the most useful being *Leucaena leucocephala*. This plant dominated in drier areas and on shallow soils but was found commonly throughout the island, in some instances in almost pure stand (Beard, 1949). It was much eaten by livestock, including small ruminants especially in the dry season when grasses dried off, and no toxicities have so far been recorded. This species probably contributed greatly to the well-being of Antiguan livestock (Keoghan, undated b). In similar ecological conditions in the Caribbean, i.e. parts of Jamaica, the Bahamas, Cayman Islands, and the dry areas of the volcanic islands, the same situation exists. The main associated grasses were *Dichanthium aristatum* and *Bothriochloa pertusa* and in well drained areas, *Panicum maximum*. The tree legumes *Acacia nilotica, A. lutea, A. farnesiana, A. tortuosa*, and *Prosopis* spp (Beard, 1949) were very prolific, providing useful browse material. However, if not kept under control, they could quickly convert the pasture into a thorny thicket (Beard, 1949). The species were apparently being widely dispersed through the livestock, which eat ripe pods and excrete the seeds.

The research in Antigua involved collection of potential forage legumes, particularly in the drier Caribbean and Yucatan in Mexico and testing these along with accessions from the CSIRO of Australia and CIAT in Colombia. The collection consisted mainly of *S. hamata, T. labialis, C. ternatea, L. leucocephala, Glycine wightii* and *Desmanthus*. Among the observations made were yield, seasonal productivity, tolerance to diseases, insect pest and drought resistance, palatability, persistence under cutting and grazing and ability to form suitable grass/legume associations. One of the main soils on which the work was carried out was Fitches clay (Table 1), which is common in Antigua. Information was recorded on more than 100 grasses and 300 legume accessions on five sites representing the different ecological environments on the island. The most promising species of legumes and grasses from the trials were tested for their performance under a grazing regime (Devers, 1979; Devers and Keoghan, 1978) and on the basis of these studies, recommendations were made for improved pasture species on the very fine textured, high pH soils of Antigua. Similar studies were later carried out on volcanic islands such as St. Lucia, Dominica and St. Vincent (Keoghan, 1980a).

Among the useful findings from the work so far is that *S. hamata* (Caribbean) is susceptible to anthracnose, which is in agreement with Kretschmer (1984), but due to the normally relatively dry atmospheric conditions in Antigua the incidence of the disease is important only in wetter years, which occur on average once in 5 years. For the same reason, *Rhyzoctonia* on Siratro is not a problem in climates such as that of Antigua. After several years of testing, the following recommendations were made for improved pasture management in Antigua on heavy clay soils in areas with 875 to 1750 mm annual precipitation and for other areas with similar conditions elsewhere in the Caribbean (Keoghan, 1980b; undated a; Keoghan and Devers, 1977).

Long-term pasture: The legumes recommended were *S. hamata* (Caribbean hamata), *Centrosema* sp. (CIAT 438), *T. labialis, G. wightii* (Clarence, Tinaroo, Cooper and CPI 52614) and *L.*

leucocephala (CIAT 871). The grasses recommended to grow in association with Caribbean hamata were *Cynodon* sp. (Coast Cross 1), Calle, Bermuda and Star grasses, green panic (*Panicum maximum* var Trichoglume), Sabi grass (*Urochloa mozambicensis*) and Dubi grass (*Urochloa balbodes*).

Short-term pastures with large early legume production: The legumes recommended were Siratro (*M. atropurpureum*), *Desmodium distortum* (CIAT 355), Phasey bean (*M. lathyroides*), *Centrosema pascuorum*, *C. schotti*, *Clitoria ternata*, *Desmanthus virgatus* and *Teramnus uncinatus*.

The recommended grasses are the same as for long-term pastures, above.

Cut-and-carry systems: As for (b) above plus *L. leucocephala*, *G. wightii* and *T. labialis*.

Protein banks: Suitable legumes are *L. leucocephala*, *Desmanthus virgatus*, *G. wightii*, *M. atropurpureum*, *C. ternatea*, *Centrosema* sp. (CIAT 438) and *C. schottii*.

Based on similar work on islands which have soils derived from volcanic materials and generally more rainfall e.g. St. Lucia, St. Vincent and Dominica, combinations of grasses and legumes are also now available for long-term pastures, short-term pastures with high legume production, cut-and-carry systems and protein (fodder) banks (Keoghan, 1980a).

Techniques were also developed for over-sowing the selected legumes into native pastures using minimum mechanical tillage (Keoghan, 1981).

Production of protein supplements: Several types of high-protein meal have been produced from dried legumes using techniques that do not necessarily require expensive technology. Plants are harvested, sun-dried and the leaves shaken off. This leaf material can be mixed with other high-energy feeds, such as grain, to produce more balanced rations for high production, particularly for dairy animals or pigs.

The meal could be produced in association with seed production. The crude-protein content of meals produced from several prolific legumes ranged from 10 to 23%.

Seed production: Staff have been trained at CIAT in seed production technology so that the project has acquired this essential expertise. Production of seed of most of the recommended species mentioned above is in progress to make the material available to farmers in the various ecological zones for which the recommendations have been made.

Belize

In the mid 1960s there was a serious attempt to introduce forage legumes in a systematic way in Belize (Snook, 1968; 1969 a,b) through an FAO Project but after its conclusion the impetus was not maintained. Through an internationally funded project already referred to, research was started again in 1972 and is continuing.

The strategy involved testing species collected from within Belize and from the Caribbean and Central American region, and those obtained from centres such as CSIRO and CIAT. Observations were made in introduction plots for at least one year during which growth characteristics, dry-matter yield, flowering and seed production, incidence of diseases and insect attack etc were studied. Promising species were then selected and planted in single plant experiments in the various soils and ecological environments that were considered to be available for pasture development, and observations were made on productivity and plant behaviour. Selections from these experiments were then planted in strips in native or established pastures where further observations were made on yield, competitive ability, spread, persistence, palatability and other aspects. This was a critical stage of assessment since it provided information on the yield potential and persistence of the various species under the stress of frequent cutting. Some of the results obtained have been recorded by Lazier (1978; 1980a, b; 1981 a,b,c). Selections were finally made from these for use in pastures and their role in animal production was assessed.

The various experimental sites, i.e. introduction area, single plant and strip trials, remained fixed and as soon as plants failed, they were replaced by more recent introductions. Also, plants that had been found to be promising at any stage were removed to make room for newer introductions at an earlier stage of assessment. Using this dynamic system of screening, over 2000 introductions have gone through the system in about 10 years, with about 15 species having been shown to be promising at most stages: These are now being recommended for introduction into pastures in the various soil and ecological conditions to which they are adapted.

Two of the important groups of soils of Belize are target soils for pasture development, these being Ultisols, the so-called Pine Ridge soils, properties of which are shown in Table 1, and Vertisols which are similar to the Antigua soil (Fitches Clay). The major differences between the two Vertisols are the deeper profile and much lower P and higher clay contents of the Belize soil. Higher rainfall in Belize adds to the problems for research in pasture establishment on these clay soils. The programme concentrated on these two soil groups but has had greater success with the Ultisol to date and progress has been substantial. As a consequence of the work, prospects are now much better for an improved livestock industry in the country given satisfactory marketing conditions. Ecological characteristics of the area and details of the pasture research and development work are given below.

The Low Pine Ridge of Belize represents an ecological zone extending throughout the north/south length of the country, occupying over 300 000 ha of land. The area is essentially undeveloped at present and there is keen national interest in encouraging livestock farming on it. As a result, it was one of the main areas for research on the role of legumes in pasture development. The soil is typically a planosol (Ultisol, Table 1) with a light-textured surface layer underlain by a clay pan (Jenkin et al, 1976). The area formed the old coastal plain before the end of the Quaternary Period and is representative of much larger areas in Guyana, Suriname and Venezuela. The land is generally low lying and the soil becomes completely water-logged during the wet season. The natural vegetation consists of low-growing, very hardy grasses and sedges with the same species as the Aripo Savanna in Trinidad (Ahmad and Jones 1969 a,b). The tree species, which are sparsely distributed, comprise stunted, very slow growing Caribbean pine (*Pinus caribbea*), calabash (*Enallagma latifolia*) and palmetto palm, the association being described as pine-palmeto tree savanna vegetation.

Legumes selected from single plant trials were planted in strips in the native vegetation and fertilized with a total of 63 kg of triple superphosphate/ha per year applied in three installments each year. The production of each species (dry-matter yield, spread, persistence etc) was assessed on an arbitrary scale of 0-10 over 1 to 3 years, each period of observation being 6 weeks.

Desmodium ovalifolium, C. gyroides, G. striata performed well and will be evaluated further under grazing, while *S. guianensis* (Cook), *M. atropurpureum*, a Siratro and *C. pubescens* were considered not suited to this environment but were nevertheless included intially in the first grazing trial due to seed availability.

The selected species were planted in 6 ha paddocks by harrowing the land and broadcasting the seeds. Fertilizer was applied at the rate of 63 kg of triple superphosphate/ha per annum in three installments. The effects of these treatments on the flora are presented in Table 2 and on animal production in Table 3. The fertilizer treatment and introduced legumes caused major changes in floristic composition, resulting in an increase in the non-planted (native) legume flora and decrease in sedges. The visual effect of these changes is very striking indeed. It is interesting to note that in 1982, fertilizer alone (Paddock

Table 2. Dry-matter production as influenced by planted legumes and fertilizers.

Species	Paddock A	B[1]	C	D	E	F
			9/6/79 - 9/10/80			
Siratro	244*	..	..	..	113	..
S. guianensis (Cook)	9	604*	..	138	58	..
S. guianensis (Endeavour)	7	16	..	459*	268*	..
C. gyroides	..	..	2302*	..	..	..
P. phaseoloides	..	..	..	..	707*	..
Native legume	80	79	..	63	29	6
P. maculosum	132	30	..	14	19	12
Sedges + grasses (native)	520	589	..	526	227	573
Weeds	422	394	..	250	263	167
Total - legumes+grasses(new)	472	729	2302	674	1194	17
Total - weeds	942	983	..	776	490	740
Total dry matter g/2.5m^2	1414	1713	2302	1450	1683	758
Planted species as % of total dry matter	17	35	100	31	57	..
Total dry matter (kg/ha)	5640	6840	9200	5800	6720	3040
			Jan. - Dec., 1982.			
Siratro	143*	..	..	..	42	..
S. guianensis (Cook)	..	56*	..	..	..	..
S. guianensis (Endeavour)	..	..	..	33*	..	..
C. gyroides	..	..	1570*	..	..	..
P. phaseoloides	..	..	..	..	887*	..
Native legume	26	77	..	5	10	9
P. maculosum	2	..	..	..	..	9
D. adscendens	132	..	..	..	..	.
C. caeruleum	2	..	..	..	..	..
M. lathyroides	..	..	..	47	..	..
A. americana	..	..	..	..	17*	..
Sedges + grasses (native)	239	585	..	331	76	1060
Weeds	268	179	..	194	84	15
Total-legumes+grasses(new)	309	1570	1570	302	956	18
Total - weeds	597	764	..	525	160	1075
Total dry matter (g/2.5m^2)	906	921	1570	827	1116	1003
Total dry matter (kg/ha)	3300	3300	5690	3000	4040	3950
Planted species as % total dry matter	15	6	100	4	81	

Sources: Neal (1979); Parham (1981); Parham (1984).

* Planted legumes in respective paddocks.

\+ Paddock F - un-fertilized native

1. Paddock B 1982 considered as fertilized native pasture due to failure of Endeavour in 1980.

B) caused significant changes in the floral composition. These measurements were made 5 years after the commencement of the experiment with the premise that, after that time, equilibrium would have been established in the flora.

The effect on animal production (Table 3) emphasised the poorness of the native vegetation (paddock F) and its inability to sustain production. The paddocks in which legumes were introduced or which were fertilized without legume introduction resulted in very large increases in liveweight gains. The data are only preliminary and such experiments would have to be continued for a longer time before conclusive results could be obtained. It is planned to introduce improved grasses in these paddocks on the assumption that by this time the legumes have increased soil fertility sufficiently to support improved grasses. In this way, the pasture would be further up-graded. Species which can now be recommended with confidence for these low-lying,

Table 3. Annual liveweight gains as influenced by forage legumes in Belize (11/3/82 to 9/2/82).

Pasture	Grazing intensity ha : head	LWG[1]/ animal (kg)	DLWG[2]/ animal (kg)	LWG (kg/ha per yr)
A(Siratro)	6 : 4	155.0	0.47	57
B (Fertilized-native)	6 : 4	143.1	0.58	71
C (*C. gyroides*)	6 : 4	166.9	0.50	61
D (*S. guianensis*)	6 : 4	151.9	0.44	53
E (mixture - mainly *P. phasedoides*)	6 : 4	211.5	0.63	77
F (unfertilized native)	24 : 2	15.7	0.05	2

1. LWG = liveweight gain.
2. DLWG = daily liveweight gain.
Sources: Parham (1984); (1980); (1981).

poorly drained soils include *C. gyroides, P. phaseoloides, D. ovalifolium, D. heterophyllum* and *D. heterocarpon*.

For the Vertisols, the extreme soil-water relationships between wet and dry seasons, very low levels of P and the difficulties of establishing small-seeded legumes on them have proved to be serious problems.

Experiments on the role of small quantities of P and K fertilizers in influencing or increasing the legume flora have also indicated that this can be achieved on the Vertisols if the treatments are maintained for a long time.

Extension phase: As a result of the recent work in Belize and Antigua, legumes have been identified that can now be recommended for some of the important ecological zones and in other areas of the Caribbean with similar environmental conditions. As outlined above, the confidence with which these recommendations can be made is not the same for all the major zones. In Belize itself, the extension phase is now active and trials and demonstrations in farmer' fields are being established. In anticipation of an increase in demand, seed of the selected species is being produced, based on the technology developed at CIAT. Essentially, the evaluation process worked out in Belize and successes of the project have at least partly inspired the establishment of a forage improvement network for Central America, with direction from CIAT and support from the IDRC.

Guyana

There have been few introductions of pasture legumes into Guyana, an important one being made in the early 1970s to aid beef production at Ebini. Several species were selected at random and planted in improved pastures on brown sandy soils (Table 1). Growth was good in the early stages but all the material eventually died except for *C. mucunoides*.

In the late 1970s a new start was made in Guyana, this time to aid milk production at Moblissa. The introduced legumes were planted on sandy and extremely infertile soils (Table 1). In brief, of the legumes introduced, *S. guianensis* persisted for 2 to 3 years under both cutting and grazing regimes and *Indigofera hirsuta, M. artropurpureum, D. uncinatum* and *C. pubescens* disappeared rapidly under moderate stocking rates and grazing pressures. On these poor soils, only *C. mucunoides* still persists, becoming a weed in some areas (Surujballi et al, 1981). The authorities are concerned that it is not very palatable but the advantage of this is that it is eaten sparingly, thus ensuring its survival and continued contribution to the nutrition of the stock and to the improvement of the extremely infertile soil.

There is now a more systematic approach to establishing suitable legumes through highly selective testing. Additional species being assessed include *D. ovalifolium, P. phaseoloides, D. heterocarpon, D. heterophyllum, S. capitata, D. distortum, Aeschynomene histrix*, and *C. macrocarpum*.

Trinidad

At present there is only academic interest in the role of legumes in pasture production in Trinidad. Material from CIAT is being tested routinely and legumes such as *P. phaseoloides, C. pubescens, C. mucunoides and P. lathyroides* are endemic and contribute to pasture productivity, but their true role has not yet been assessed systematically. Trinidad is participating in the CIAT network mentioned above.

Barbados

With one of the highest population densities in the world, there is little land available for pasture production in Barbados. The soils are all clays (Vertisols) and calcium saturated. *G. wightii* has proved to be outstanding in persistence and growth in association with improved pasture grasses in experiments.

The Greater Antilles

These islands include Jamaica, Puerto Rico, Hispaniola (Dominican Republic and Haiti) and Cuba. In Jamaica and Puerto Rico, the tradition of high levels of nitrogen fertilizers on essentially grass pastures still persists. Current research is aimed at finding grasses that would use fertilizer nitrogen most efficiently. Due to continuous use of nitrogen fertilizers over a long period of time and intense competition from grasses, native legumes are not usually an important component of the flora of pasture managed in this way. In less intensive systems in which less fertilizer is used, the dominant Guinea grass pastures have a good legume association consisting of *Desmodium* spp at a lower level, *Centrosema* spp. and *Macroptilium* spp. as twining legumes and *L. leucocephala* for browse.

In the Dominican Republic, *Centrosema, Clitoria, Macroptilium, Teramnus* and Caribbean hamata are important native legumes on predominantly calcareous soils. It was noted that *Centrosema* spp combine well with *Cynodon dactylon*. In natural pastures which consist mostly of Guinea grass, a combination of these legumes is important. (Wagner, 1981).

A great deal of emphasis has been placed on pasture legumes in Cuba, where they are considered to be important. *Desmodium* spp and *Glycine wightii* are prolific on red soils, presumably derived from limestone, *Centrosema* spp in brownish grey soils in wetter areas and *L. leucocephala* in clay soils (Vertisols), as in Antigua. *G. wightii* and *T. labialis* are reported to be very promising on calcareous soils as in the rest of the Caribbean and *G. wightii* combines better with the native grass *Bothriochloa/Dichanthium* than with Pangola grass (Menendez and Martinez, 1980; Lopes et al, 1981).

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THE INTRODUCTION OF FORAGE LEGUMES INTO GAMBIAN FARMING SYSTEMS

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ABSTRACT

The Gambia has a short rainy season (3-4 months) and a long dry season. The present practice of unregulated pastoralism and the lack of a land-tenure system results in under-utilisation of livestock and overgrazing of native range-lands. Prior to 1981 little research had been conducted in forage agronomy. The Mixed Farming Project, with its focus on livestock and maize production, started in 1981 and included component research on forages and range ecology. Legume introduction plots were established around the country in 1982. Only *Stylosanthes* species and a grass, *Andropogon gayanus*, have shown any promise under local conditions but communal grazing and no fencing has made deferred grazing or fodder banks impractical. Intercropping forage legumes with maize was begun in 1984 with a view to providing dry-season grazing. Although research station results, grazing and feeding trials show the excellent potential of forage legumes in The Gambia, until there is ownership of land farmers will not include forages in their farming systems.

INTRODUCTION

The Gambia is the smallest country on the African continent, sandwiched into Senegal on the west coast between 13^{o} and 14^{o}N. The Gambia consists of land on either side of the river Gambia, never more than 30 km north and south of the river and running east from the coast approximately 300 km. Total precipitation has been 1000 to 1200 mm annually, but in recent years annual precipitation has dropped to 600 to 800 mm. The rains start in late June and last for 3 to 4 months. The long dry season of 8 to 9 months causes serious problems in terms of livestock feed resources.

A major survey (Dunsmore et al, 1976) estimated that the total dry season fodder resources in The Gambia were able to support about 177,500 adult cattle equivalents annually. The main fodder resources were: crop residues, floodplain grazing, early fallows and upland bushland. However, since 1974, the cattle population has increased from 200,000 to 300,000 head, the area of floodplain grazing has been reduced due to an increase in cultivation of irrigated rice, the population has increased by 3.4% annually, the areas formerly left fallow are beginning to be continuously cropped, and bushlands are being cultivated.

The Mixed Farming Project (USAID/CID/GOTG) started in The Gambia in 1981 with the objective of effecting a better integration of crop and livestock production, thereby increasing the availability of forage for livestock. The project has worked in three areas: maize production (grain for humans, stover for livestock), forage agronomy and range ecology, with supporting socio-economic studies. Prior to 1981 little research had been done on forage and range resources in the Gambia.

MATERIALS AND METHODS

From 1982 to 1984 the forage programme concentrated on introducing legumes. Seed was obtained from CIAT and planted at three sites across the country representing three major soil associations. In 1983, the plantings were expanded using seed from the 1982 season. Also in 1983, seed from ILCA was planted in small plots at one site. Half-hectare plots were added at four Mixed Farming Centers, a rural training centre and at one village site. The survival of the accessions at three sites as of 1985 is shown in Table 1. None of the plots were irrigated or innoculated with rhizobia and only minute quantities of P were broadcast on the plots.

Table 1. Species, origin and survival of legumes in introduction trials at three sites in The Gambia, 1982-85.

Species	Location[a]		
	Yundum	Sapu	YBK
Stylosanthes humilis - local	x	x	x
Stylosanthes hamata - Australia	x	x	x
Stylosanthes hamata - local	x	x	x
Stylosanthes hamata - ILCA	x		
Stylosanthes scabra - Australia	x	x	x
Stylosanthes guianensis - Australia	x	x	x
Stylosanthes guianensis - cv. Endeavor	x		
Stylosanthes guianensis - cv. Schofield	x		
Stylosanthes guianensis - CIAT	x		
Stylosanthes macrocephala - ILCA	x		
Stylosanthes capitata - ILCA	x		
Stylosanthes capica - CIAT	x		
Aechynomene histrix	x	x	x
Macroptilium atropurpureum	x	x	
Leucaena leucocephala - Australia	x	x	x
Leucaena leucocephala - local	x	x	x
Leucaena leucocephala - Philippines	x	x	x

a. An x indicates established, surviving plot as of July 1985.

Between 1982 and 1984 the range programme concentrated on developing deferred range areas for dry-season grazing and on improving those areas through seeding and root planting of grasses (*Andropogon gayanus, Cenchrus ciliaris*) and seeding legumes (*Stylosanthes hamata* and *S. humilis*).

From 1982 to 1985, feeding trials were conducted at the Yundum research station during the dry season with N'Dama cattle using various types of crop residues, including groundnut hay and stylosanthes hay. In 1983, a village-level feeding trial was started which used a combination of deferred grazing on improved rangeland and crop residues to feed cattle from January through June. This programme was extended to three more villages in the 1984/85 dry season but was restricted to the period of greatest feed shortage, between 15 March and 15 June.

In the 1984 planting season, an experiment was conducted on intercropping maize with cowpea (*Vigna unguiculata*), groundnuts (*Arachis hypogea*) and lablab (*Dolichos lablab*). During the 1985 dry season, two experiments with maize and cowpea were carried out under irrigation. For the 1985 rainy season, two maize/cowpea experiments, one sorghum/cowpea and one maize/stylosanthes experiment (*S. hamata, S. humilis* and *S. scabra*) have been planted at three locations, and one alley cropping experiment (maize, leucaena, gliricidia, and sesbania) has been planted. Also in 1985, a maize/cowpea intercropping package was introduced to 30 Women's Societies in the country and 15 on-farm maize/cowpea intercropping trials are being carried out by the Maize Unit of the Mixed Farming Project.

Legume grazing trials were conducted at three locations for several months in both the dry and the wet season in 1984. These trials used work oxen, sheep and goats and were primarily to determine the platability of the different legumes and to assess the animals' preference among the species.

RESULTS AND DISCUSSION

Legume introductions

The introduction plots at Yundum, Sapu and YBK were kept weed-free. At the other sites, including village fodder banks, labour for weeding was available only sporadically, and these sites appeared to have been taken over by bush. However, a closer examination showed that the *Stylosanthes* species, *S. hamata* and *S. humilis* in particular, established almost complete groundcover below the bush. None of the other legumes persisted in the relatively untended plots. Even with weeding at the research station plots, many legumes did not survive, because of either inadequate moisture or failure to reseed. *S. sympodialis, Zorina* spp., *Centrosema* spp. and *Desmodium* spp. did not regenerate at any site. At Sapu, *Siratro* sp. regenerated, while at YBK and Sapu *Aeschynomone* sp. recovered. *S. scabra* was the most productive in terms of biomass, remaining green well into the dry season and greening-up quickly after the first rains, but it was unpalatable.

The performance of leucaena was disappointing. Germination was often poor even with seed treatment, seedling vigor was poor, rabbits and termites devastated many plots, maximum height after 3 years was 2 m with few branches, and it was unpalatable to all classes of livestock. However, it has been a prolific seeder. Research on this plant is continuing. The alley-cropping experiment mentioned earlier (with maize, leucaena, sesbania and gliricidia) will start with 6-month-old leucaena seedlings in an attempt to overcome the poor germination and low vigor of leucaena grown from seed. The Forestry Department is planting seedlings in village garden plots as fences and borders, and for use as fuel, fencing and feed.

Intercropping experiments

With increasing pressure on land around the villages and the decrease in amount of land under fallow, interest in intercropping of cereals and legumes has increased. Intercropping is a common practice in The Gambia, usually with sorghum and millet or maize and millet, but frequently with cereals and groundnuts and occasionally with maize and cowpea. Although research on intercropping has been conducted at Sapu for many years, no recommendations have yet been made to farmers.

Legume seed is in short supply, which is a serious constraint in the forage programme and even more so for farmers. Several experiments were designed for 1985 using cowpea as an intercrop with maize. Cowpea seed of several varieties is readily available, although it is expensive compared with other grains as it is a preferred food. Herbicides and pesticides are not readily available, so one objective was to determine the best time of planting cowpea to avoid disease and pest problems. Another objective was to determine the best crop geometry (between rows, within rows, alternate rows of cereal and cowpea, double rows of cereal and cowpea) for intercropping. Preliminary results indicate that planting cowpea either between or within the rows of maize has little effect on maize yield, but cowpea planted between the rows flowers sooner while cowpea planted within the rows is easier to cultivate, weed and harvest. The 30 Women's Societies growing maize and cowpea this year are being encouraged to save the cowpea hay as well as the maize stover as feed for their small ruminants.

The *Stylosanthes* species that are adapted to The Gambia are prolific seeders and have invaded many other research plots. This ability to colonise the low-fertility, slightly acid soils may be an advantage. Farmers generally do not practise crop rotations, although they are aware that they should. The presence of stylosanthes in fields that are under continuous cereal cropping may improve the fertility of the soil as well as providing a source of feed in the dry season. A trial on undersowing maize with *S. scabra*, *S.*

humilis and *S. hamata* is being conducted at Yundum, Sapu, YBK and one village site to investigate the potential of this system.

Since previous attempts at alley cropping have been unsuccessful, it is too early to say what the results of the 1985 alley cropping experiments will be.

Feeding and grazing trials

Results of the feeding trials have been published (Hedrick and Bojang, 1983). It was found that animals could maintain weight over the dry season on crop residues of fairly low nutritive value. Table 2 shows the nutritive values of crop residues used in The Gambia. Groundnut hay is under-utilised, and is often left in the field or sold to Senagalese traders. A small amount is saved by farmers for their draught animals (oxen, donkeys, horses) but with 95% of the farmers raising groundnuts (Dunsmore et al, 1976) and many starving animals, clearly a major extension effort is needed on the management and use of groundnut hay and other crop residues.

Table 2. Crude protein, crude fibre and ash contents of some commonly available crop residues in The Gambia.

Feedstuff	Crude protein (%)	Crude fibre (%)	Ash (%)
Groundnut hay	11.9	24.4	6.3
Rice straw	4.4	28.2	20.8
Gamba grass hay	4.0	36.5	4.5
Maize stover	3.1	37.1	4.5
Sorghum stover	1.7	33.9	6.2
Maize silage	3.5	32.0	6.0

Grazing trials were conducted at Yundum, Sapu and YBK from February through December 1984. The two most preferred species of legumes were *S. hamata* and *S. humilis*. At Sapu, the goats ate most of one plot of 3-month-old leucaena seedlings once: that was the only instance that any of the livestock would eat leucaena. Paradoxically, in March 1985, when cattle were turned into the plots to graze off the standing biomass, they grazed off most of the leucaena at all three sites. The question always arises in preference trials as to whether an unpalatable plant would become palatable were it the only one on offer. Indeed, when the small ruminants were staked in plots of *S. scabra* they eventually ate that legume. It is as useful to know which species are unpalatable as palatable when considering how to provide dry-season grazing. An unpalatable species such as *S. scabra* would escape grazing early in the dry season, thus enabling it to reseed and be grazed later in the dry season when bush fallow, for example, has been exhausted.

In the village-level feeding trials, little was done with forage legumes. An attempt has been made to establish fodder banks of stylosanthes and to oversow some rangelands with stylos, but as yet this provides only a very small proportion of the feed offered to the village herds.

Constraints

The land-tenure system and poor seed availability are important constraints on the establishment of a viable forage legume component in Gambian farming systems.

Land around villages is allocated to individuals by the chief each year, and generally there is no assurance that an individual will receive the same piece of land every year. Hence, there is little incentive to improve the land through manuring, mulching, fencing or crop rotation. Grazing animals are allowed free access to all lands. Thus, there is no incentive for a farmer to plant a forage crop, since all the animals of the village would have free access to it.

Nevertheless, small steps have been taken towards developing feed resources at the village level through the deferred-grazing programme. Areas of 10-20 ha have been fenced, protected from grazing and partly improved. Farmers can see the sharp contrast between fenced and unfenced areas. One village has even tried to defer grazing on some of their rangeland without fencing and has been partly successful because the village is in a very remote part of the country. Whether this can be extended remains doubtful; an isolated village or one with a strong chief could enforce the deferred grazing and/or the establishment of fodder banks, but until title and ownership of land is a legal reality throughout the country, it will be very difficult to progress with development of pastures.

The second important constraint is lack of forage-legume seeds. The approach to this problem has been three-fold. Due to the necessity of producing results as quickly as possible, work has progressed using the dual-purpose legumes already grown in The Gambia, cowpea and groundnuts. While research continues on these crops, a major extension effort is needed to instruct farmers in their use as livestock feed. The second step has been to continue research on leucaena because of its excellent seed production. The third step has been to train two Gambians in seed production and to start a small seed multiplication unit for forage legumes, primarily stylosanthes.

CONCLUSIONS

Livestock production in The Gambia at present is a very low-input, low-output system. Cattle are not primarily raised for sale, and farmers are interested mainly in maintenance rather than production. Cattle are herded mostly by Fula, who are paid in milk, thus involving no capital outlay by the farmer. Most farmers would like to increase their herd size, but not their outlay on livestock production.

Thus, there is little scope or incentive for increasing livestock production. However, the late start of the rains in 1985 led to the death of large numbers of livestock in The Gambia, which emphasises the need for greater feed resources.

Due to the land-tenure system, farmers are reluctant to plant forage crops. While the use of cultivated pastures is not likely to be adopted in the near future, and may never have a place in Gambian farming systems, cultivated fallows and intercropping legumes with cereals should be encouraged to provide the additional feed necessary.

Introducing forage legumes into the farming systems should also have the additional benefit of increasing soil fertility, thereby increasing cereal yields. Several forage legumes have been identified that are adapted to Gambian conditions and that may be useful in a number of systems. Efforts should be made to introduce systems that include a forage legume component.

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THE POSSIBLE ROLE OF FORAGE LEGUMES IN COMMUNAL AREA FARMING SYSTEMS IN ZIMBABWE

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ABSTRACT

The Farming Systems Research Unit, entrusted with the task of developing and testing improved crop and livestock technologies for the communal farming areas, has selected two representative areas in which to carry out its programme. Mangwende is at medium altitude, has predominantly sandy soils with pH between 4 and 5, and rainfall between 700 and 900 mm per annum; Chibi has similar characteristics except that rainfall ranges between 400 and 600 mm and thus is classified as low potential. Crops grown commonly in both areas include maize, millets, sorghum, groundnuts and vegetables. Although cattle are desired by all farmers, primarily because of draught-power and manure needs, only half to three-quarters of the farmers own cattle and herds are very small. Poultry are very common in both areas whereas goats and donkeys play an important role only in Chibi. The major constraint on improving livestock management and productivity is the shortage of dry season feed in the winter due to the very low productivity of the

communal grazing areas and very low quality of crop residues, mainly grain stovers.

A review of previous research on forage legumes in Zimbabwe showed the following. *Trifolium semipilosum* and *Lotononis bainesii* persisted with various creeping grasses under cutting for 6 years and, in the absence of N fertilizer, resulted in marked increases in dry-matter yield and crude protein content of the herbage. On ploughed land *Desmodium intortum, D. uncinatum, Macroptilium atropurpureum* and the other herbaceous legumes have been shown to persist under controlled grazing or cutting and produce yields of up to 10 t DM/ha. The use of herbaceous legumes for dry-season grazing has given disappointing results because of leaf shed due to frost and of trampling of the herbage. For the reinforcement of native grazing, the ability to establish under adverse conditions is a prime requirement and *Stylosanthes* spp seem especially suitable. Under controlled grazing, *S. guianensis* var *intermedia* has increased body mass gains per hectare by up to 60%.

In one series of trials, four legumes (*Stylosanthes humilis, S. guianensis* var *intermedia, Macroptilium atropurpureum* and *Macrotyloma axillare*) were established in exhausted arable areas, now used for grazing, at 11 sites in communal farming areas. Marked responses in dry-matter yield to application of single superphosphate and dolomitic lime were recorded. Subsequent screening trials of legumes under different fertilizer and management options were started but did not produce conclusive results due to political developments prior to and during independence.

The feasibility of introducing forage legumes in the communal area farming systems depends on a number of factors: improved management of communal grazing areas; competition with crop enterprises for scarce resources including land, labour and cash for fertilizers; willingness and availability of capital to erect fences; direct and indirect pay-offs in terms of farmers' current priorities; and enthusiasm and ability of extension staff.

INTRODUCTION

The tremendous success of agricultural development in the large-scale commercial farming sector of Zimbabwe can be attributed to the skillful implementation of appropriate government policies and, to a large extent, intensive interactions and effective communication between farmers and development, extension and research officers. This relationship ensures precise definition of production constraints and researchable problems and quick feedback on the profitability and acceptability of technological innovations under practical management conditions. These inputs serve as a basis for planning research programmes. These inputs are also necessary for improving agriculture in communal farming areas. Consequently, the Department of Research and Specialist Services decided to form the Farming Systems Research Unit (FSRU) to conduct on-farm research.

The specific objectives of the FSRU are to study mixed crop and livestock production systems in two representative communal farming areas in order to identify opportunities for and major constraints on improvements of production, and to adapt, develop and test improved crop and livestock production techniques and systems on-farm.

This paper briefly describes the present farming systems and major constraints, presents a review of previous research on forage legumes in Zimbabwe, and discusses the feasibility of introducing forage legumes into the communal farming areas and its implications for future research.

PRESENT FARMING SYSTEMS AND CONSTRAINTS

The Mangwende and Chibi Communal Areas were selected for study by the FSRU because they have distinct and different biological and economic potentials. Mangwende is at an altitude of between 1200 and 1500 m, and has predominantly sandy soils derived from granite with pH ($CaCl_2$) between 4.0 and 5.0 and a unimodal pattern of rainfall. Average rainfall is between 700 and 900 mm per annum. Chibi has similar characteristics except that the altitude is between 700 and 900 m and rainfall is between 400 and 600 mm per annum. Mangwende is considered to be a high potential area and was chosen because conventional wisdom is that scarce research resources must be invested in regions where large and quick pay-offs would be likely to occur. Although Chibi is considered to be a low potential area, it was chosen because the vast majority of communal area farmers live in such areas.

The farming systems in the two areas are basically similar with respect to the combination of crop and livestock enterprises (Table 1). In Mangwende, maize is the predominant crop and cattle herds are larger than in Chibi, where the small grains [sorghum and millets (*Sorghum vulgare, Pennisetum typhoideum* and *Eleusine coracana*)], and goats and donkeys are relatively more important.

Within these farming systems there is a high degree of interdependence and interaction among crop and livestock activities. The livestock depend upon crop residues for survival during winter, and the crop enterprises are extremely dependant upon livestock for draught power for land preparation and for manure to improve soil fertility. Given the mean areas of arable land per farmer, it is estimated that each farmer requires 40 to 50 working days per year from a span of at least two animals in good condition. In addition, ploughing must be timely to exploit the early rains, otherwise maize yields could be reduced by as much as 70%. It has been shown that a minimum of 10 tonnes of manure must be applied per hectare to obtain a significant effect on maize yields (Mugwira, 1985), which would require a herd at least four times the present size to supply manure for the entire arable area. Furthermore, the quality of manure in communal farming areas is low and highly variable, consisting of up to 50% sand (Mugwira, personal communication). This could be due to the way in which farmers store and dig out kraal manure or to animals grazing too low to the ground and ingesting sand (Ward, personal communication).

Table 1. Mean areas and numbers and percentage of farmers with selected activities in the research areas of Mangwende and Chibi.

Activity	Mangwende	Chibi	Mangwende	Chibi
	Mean area (ha)/farmer with crop enterprise		Number of farmers (%)	
Arable area	2.8	2.5	100	100
Maize	1.5	0.8	100	96
Sorghum	0.2	0.4	4	54
Groundnuts	0.3	0.2	77	29
Pearl millet	0.3	0.6	4	56
Finger millet	0.3	0.4	55	75
Vegetable garden	0.3	0.4	72	50
	Mean number / farmer with livestock class		Number of farmers (%)	
Cattle	9.0	5.5	77	57
Goats	4.7	4.2	28	52
Donkeys	2.8	2.8	5	30
Sheep	1.0	7.7	2	5
Pigs	3.6	2.1	5	6
Poultry	15.0	13.1	87	79
Rabbits	4.5	4.7	10	2

Numbers in sample: Mangwende 108 and Chibi 131.

Source: FSRU Survey (1984)

In the long term, cattle provide one of the few opportunities for capital accumulation and security. Farmers use most of their cash (profits from crop enterprises or off-farm remittances) to purchase cattle. They perceive cattle as savings banks, liquid assets that can be used for emergency situations and protection against risk, and cattle serve also as a medium of exchange for formal and traditional arrangements such as bridewealth in marriages. In addition, livestock provide basic food needs in the form of milk, eggs and meat.

Because of these functions, farmers always desire more livestock and cattle in particular. From informal discussions with farmers, it seems that the optimum herd size is regarded as between 30 and 50 head per household, but very few farmers ever achieve this. The mean numbers of livestock in both areas are far below the desired herd size and a large number of farmers do not have any cattle but need them (Table 1). Consequently, the control of stock numbers would appear to be unacceptable to the vast majority of communal area farmers.

The aggregate stocking rates of communal grazing areas are approximately twice the recommended level and grazing is uncontrolled. The result is a steady decline in veld (range) condition, as evidenced by a reduction in plant vigour, changes in species composition from predominantly perennial to predominantly annual species in the herbaceous layer, little basal and litter cover and a large proportion of bare and unprotected areas. In addition, water infiltration rates are lower and erosion and loss of top soil are severe in the grazing areas. The end result is a relatively drier soil microclimate compared with areas where veld is in better condition and this reduces the overall potential productivity of the intensively used communal grazing (Kelly and Walker, 1976).

Zimbabwe has recently suffered 3 years of drought. The poor vigour of the veld did not allow sufficient herbage production to maintain cattle at the high stocking rates found on the communal grazing areas, and, as there were little crop residues due to crop failures, the livestock were particularly severely affected, with very high mortality rates. Chibi was more severely affected than Mangwende, which has a higher mean annual rainfall.

In areas where little herbaceous forage is available, cattle tend to make greater use of browse. However, the needs for timber for building and fuel for cooking and the opening up of arable areas has reduced browse availability. Consequently, with the continued degradation of the veld and the desire for increased herd sizes, the situation in the grazing areas is not likely to improve, although some form of veld management could help to slow down the degradation. Thus other forms of intervention also need to be investigated.

With respect to the future, given the human population growth rate of 3.5% per annum, the population is expected to increase by 20% by 1990, 73% by 2000 and will double by 2006. Since the labour of young children is used and is necessary to maintain household productivity and the opportunity cost of resources used in raising children is rather low, the population growth trend will continue and will have serious implications on the demand for arable areas and encroachment onto grazing areas, and will automatically result in equivalent increases in livestock numbers. In other words, barring any major demographic shift and assuming that livestock will still be essential to the farming systems, farmers will have to produce more feed either by improving the productivity of the grazing areas or by designing their cropping patterns to optimize production of animal feed.

In the light of the above, the FSRU has identified the deficiency of feed, in both quantity and quality, particularly during the second half of the dry season and the first part of the rainy season, as the major constraint to livestock development. Deficiency of feed results in poor growth, poor reproductive performance, low milk production, inefficient performance of draught animals due to poor physical condition, high mortality rates in young stock and increased susceptibility to diseases, especially in drought years (Reh, personal communication).

The principal causes of feed constraints stem from a combination of the following factors (Reh, personal communication).

1. Decreasing grazing areas due to increasing requirements for land for arable and settlement use;
2. Increasing cattle numbers due to the economic and social importance of cattle in the farming systems and due to traditional rights to graze unlimited numbers of livestock;
3. Communal use of grazing land and stubble fields with no defined responsibility for adequate management of this land;
4. Insufficient and inefficient use of crop residues, with a strong emphasis on poor-quality cereal stover;
5. Lack of specific fodder production on arable land due to its low productivity and limited size per household, thus requiring all land for subsistence and commercial production; and
6. Lack of supplementary feeding due to a lack of cash and to the low importance of commercial production (milk and beef) from the cattle herd.

In order to ascertain the relevance of the above assumptions and to identify possible solutions to the feed problem, a review of previous research on component technology development with regard to forage legumes was made, the results of which are outlined below.

REVIEW OF RESEARCH ON FORAGE LEGUMES

From the early days of commercial farming in Zimbabwe there have been repeated attempts to select legumes that could be grown successfully in grass-legume pastures under local conditions. Initially, these attempts were centred largely on the clovers and were purely observational. Over the years a wide range of both temperate and subtropical legumes were tested. These were mainly in nursery plots although a few were also included in cutting trials and in grazed pastures. Results were generally disappointing.

One of the first long-term trials in Zimbabwe to demonstrate clearly a benefit to the grass from growing it with a legume was that of which the first 3 years' results were reported by Clatworthy (1970). Six creeping grasses were grown alone, or with Beit lotononis (*Lotononis bainesii*) or with Kenya white clover (*Trifolium semipilosum*) with nitrogen applications of 0, 112 or 224 kg N/ha per year. The trial was harvested three times each year (barring drought or accidents) and one-third of the nitrogen was applied at the start of growth of each harvest. A total of 16 harvests were taken over 6 years. The legumes persisted well for this period, which included two very dry years, and produced marked increases in yield and crude protein content from the plots receiving little or no nitrogen (Table 2). Of particular interest was that at several harvests, yields of grass were greater from the plots containing legume than from the equivalent plots without legumes. In a cutting trial, this could have resulted only from the release of nitrogen from the legume, presumably as a result of root die-back over the dry season.

The results of that trial gave added impetus to attempts to select pasture legumes for use in local farming systems. Barnes (1966) produced a short list of promising legumes for the high rainfall sandveld of Zimbabwe, including *Desmodium intortum*,, *Beit lotononis, Stylosanthes fruticosa, S. guianensis* and Kenya white clover. Other legumes have been added to this list in the light of experience gained in screening trials laid down on ploughed land at Grasslands Research Station (near Marondera), Henderson Research Station (near Mazowe) and Makoholi Experimental Station (near Masvingo) (Clatworthy, in preparation). Over 4 years the legumes were sampled two or three times per season. At each sampling, quadrats were cut from each plot before cattle were allowed to graze the legumes. After grazing, the remaining herbage was slashed with a rotary mower. At the two high rainfall sites *Desmodium* spp. were the highest yielding legumes, with *D. intortum* especially productive. Yields greater than 8 t DM/ha per year were obtained regularly. On

Table 2. Mean annual dry-matter (DM) yields and crude protein (CP) percentages when six creeping grasses were grown at three nitrogen levels with and without Beit lotononis (*Lotononis bainesii*) and Kenya white clover (*Trifolium semipilosum*).

Treatment	kg DM/ha per year			Mean CP
	Grass	Legume	Total	(%)
Without N fertilizer				
no legume	2320	-	2320	8.63
+ lotononis	2215	1880	4095	12.60
+ clover	2445	995	3440	12.09
112 kg N/ha.yr				
no legume	4700	-	4700	9.51
+ lotononis	4580	745	5325	10.62
+ clover	4740	645	5385	11.20
224 kg N/ha.yr				
no legume	7730	-	7730	10.84
+ lotononis	7100	570	7635	11.21
+ clover	7045	305	7350	10.89

Source: Clatworthy (unpublished data).

the poorer soils and with the lower rainfall at Makoholi, Siratro (*Macroptilium atropurpureum*) and Archer (*Macrotyloma axillare*) were the only legumes to persist and produce reasonable herbage yields (Table 3).

This trial differed from the true grazing situation in that the plots were defoliated severely over a short period and then allowed to regrow for a long time. However, the yields obtained may provide an indication of those that could be obtained in a "cut-and-carry" system.

Table 3. Mean annual dry-matter yields (kg DM/ha/yr) of legumes over 4 years at three sites in Zimbabwe.

Legume species	Grasslands	Henderson	Makoholi
Alysicarpus rugosus		3485	
Cassia rotundifolia			455
Clitoria ternatea			0
Desmodium intortum	8080	5985	
D. sandwicense	5700	3990	150
D. uncinatum	5135	4510	175
Galactia striata	525	1375	
Lotononis bainesii	1325	1560	95
Macroptilium atropurpureum	540	2570	1560
Macrotyloma axillare	3230	3025	1720
M. uniflorum		175	
Neonotonia wightii	2415		
N. wightii		2390	35
Stylosanthes fruticosa			210
S. guianensis (Schofield)	40	1505	
S. guianensis (Oxley)	1500		490
S. humilis			5
Teramnus labialis	1510		
Trifolium semipilosum	605		
Vigna vexillata		1435	
V. vexillata			10

Source: Clatworthy (unpublished data).

In the communal areas of Zimbabwe there are usually no fences sub-dividing the arable areas, so that if forage legumes are sown on a portion of the cultivated land, grazing them during the growing season becomes virtually impossible. Under these circumstances, legumes on arable land are likely to be used either as cut-and-carry fodder or for grazing during the dry season. For both of those roles a legume with an upright growth habit would have distinct advantages.

One example of disappointing results obtained from grazing herbaceous legumes during the dry season only is provided by a trial at Henderson Research Station (Clatworthy, 1984). Veld reinforced with Silverleaf desmodium (*Desmodium uncinatum*) and veld left undisturbed were used for overwintering weaner beef steers. Although in some seasons almost half the herbage on offer was silverleaf desmodium, unsupplemented steers lost body mass over the dry season (less on the reinforced grazing than on the control) and only started to gain when plants started making new growth from October onwards. The poor results from the silverleaf desmodium were ascribed to leaf shed after frost and to loss of herbage from trampling. It is suggested that a legume with an erect growth habit would be less affected in these ways.

One erect legume that has been used in trials at Henderson Research Station is Horse marmalade (*Desmodium discolor*). Indications of the yields which could be obtained from this legume in a cut-and carry system are shown in Tables 4 and 5 (Mills, unpublished data).

Table 4. Effects of time of harvest on total dry matter yields (kg DM/ha/yr) of Horse marmalade (*Desmodium discolor*) at Henderson Research Station.

Season	Time of harvest						
	Dec	Jan	Feb	Apr	Dec & Feb	Dec & Apr	Jan & Apr
	kg DM/ha/year						
1964/65	1140	4530	8090	8820	4340	7080	5800
1965/66	2195	2090	5625	7135	2685	4570	4280
1966/67	2830	3145	5460	1945	1400	1145	1070

Source: Mills (unpublished data).

Table 5. Effects of time of harvest on leaf dry matter yields (kg DM/ha/yr) of Horse marmalade (*Desmodium discolor*) at Henderson Research Station.

Season	Time of harvest						
	Dec	Jan	Feb	Mar	Apr	May	Jun
	kg DM/ha/year						
Cut once only							
1964/65	2081	3514	5740	4985	3146	678	261
1965/66	3233	1704	1210	1001	910	1133	-
Cut for silage in January and one other cut							
1964/65			300	1316	1868	3591	2701
1965/66			184	1258	1045	2710	-

Source: Mills (unpublished data).

The results show that Horse marmalade can produce substantial quantities of herbage of at least reasonable quality and that cutting the plots in mid-season resulted in considerably greater yields of leaf in the early dry season.

From 1951 to 1956 Pigeon pea (*Cajanus cajan*) was used to provide browse during the early dry season at Grasslands Research Station. Depending on the quantity of herbage available at first stocking and the severity of frost, steers gained an average of 0.22 to 0.34 kg/steer per day over a 30- to 90-day period (Mills, 1961). This was better than the performance of steers on lightly fertilized grass pastures, on which steers gained only 0.09 to 0.18 kg/steer per day for the same period. Recently, work has started with *Leucaena leucocephala* for use as an early dry season browse, but as yet no results are available. Both species are sensitive to frost and so their use in this role would be in warmer, frost-free areas.

Another potential role of legumes in communal area farming systems is for the reinforcement of veld which is used mainly during the growing season. A large part of the feed during the dry season is provided by crop residues on arable lands. Screening trials of legumes under grazing have shown that although a number of legumes are suited to the heavier soils at Grasslands Research station only Oxley fine-stem stylo (*Stylosanthes guianensis* var *intermedia*) persisted under heavy summer grazing and in fact increased in density through establishment from shed seed (Clatworthy, 1980). To measure the effect of veld reinforcement with Oxley stylo on animal performance at Grasslands Research Station, half of a 24 ha block of reverted land was seeded with stylo on disced strips and half left untouched. Weaner steers were brought onto the veld each June and run on the trial for a year before being removed for pen-finishing. The trial ran for 7 years. The reinforced veld could carry about 20% more steers than the control plot and the steers gained about 40 kg per head more over the year. These factors combined to result in a 60% greater body mass gain per hectare from the reinforced veld. However, it is doubtful whether an increase of this magnitude would be detectable by peasant farmers in a communal grazing situation.

TRIALS IN COMMUNAL FARMING AREAS

In 1975-76 a series of trials with legumes and different fertilizer treatments were conducted at 11 sites in communal farming areas in Masvingo Province. The trials were sited on areas that had been cultivated previously but had been exhausted by continued exploitative cropping. The aim of the trials was to select legumes that could grow on these areas, with the short-term aim of improving the quality of the diet of grazing animals and with the long-term aim of restoring the fertility of the soil to a level at which arable cropping would again be feasible.

The legumes used in these trials were Archer, Siratro, Oxley stylo and Townsville stylo (*Stylosanthes humilis*). The fertilizer treatments were nil, 200 or 400 kg/ha of a 1:1 mixture of single superphosphate (8.14% P + 12% S) and dolomitic limestone (> 11% Mg) or 400 kg/ha of the mixture plus 2 t of kraal manure/ha. The trial areas were ploughed before sowing the legume seed. At the end of the establishment season the density of the legumes in each plot was measured. The fertilizer treatments had no effect on the number of seedlings, but there were marked differences among the sites, among the legumes and in the order of the legumes at the various sites. Townsville stylo showed the greatest variation in density between the sites and Archer the least (Table 6).

Table 6. Plant density (plants/m^2) of four legumes sown on ploughed land at 11 sites in Masvingo Province of Zimbabwe in 1975/76.

Site	Legume			
	Townsville	Oxley	Siratro	Archer
1. Chivero	17.34	17.25	14.19	10.16
2. Chipinda	9.56	12.31	10.06	11.66
3. Gurajena	16.45	22.12	22.34	8.62
4. Gweriko	10.41	12.56	12.28	8.88
5. Mohohoma	7.00	12.66	8.78	11.16
6. Mamvura	8.25	9.22	14.63	18.00
7. Mazungunye	7.09	10.28	13.44	11.53
8. Muswere	7.53	11.38	16.06	15.72
9. Mutakwa	22.59	20.75	25.66	12.41
10. Serima	3.69	11.81	7.13	13.41
11. Tagwira	5.53	7.38	12.19	17.41

Source: Clatworthy (unpublished data).

At the end of the following season quadrats were harvested from every plot at nine of the sites and the herbage was sorted into legume, grasses and dicotyledonous weeds. At all sites there were large differences among the yields of the different legumes. At all but two of the sites the fertilizer treatments affected legume yields and at five sites the legumes reacted differently to the fertilizers. Archer and Siratro produced the greatest dry-matter yields (Table 7).

It had been intended to open the plots to grazing for all but a 6-week period during the growing season each year. At the end of this period the plots would have been sampled to assess the productivity and persistence of the legumes under grazing. Unfortunately, events in that area resulted in the trial being abandoned.

INTRODUCTION OF FORAGE LEGUMES INTO FARMING SYSTEMS

In order to evaluate the technical and economic feasibility of introducing innovations into farming systems, it is necessary to identify their advantages (benefits) and disadvantages (problems or conflicts) as the potential users see them.

The possible introduction of forage legumes to complement or reinforce grazing areas requires feasibility analysis at the community level since such decisions would not lie within the domain of any particular household but rather with the community at large who share rights to a defined grazing area. Farmers realise the problems of overgrazing and degradation of the veld and in the past have set up grazing schemes (Froude, 1974; Danckwerts, undated). However they no longer have child labour for herding due to schooling, and although they are interested in paddocking and using improved management, it is unlikely that rotational grazing would substantially increase forage production because of the present poor condition of the veld (Cleghorn, 1966) and the very high stocking rates (Hill, 1982). Consequently, the

Table 7. Soil characteristics, dry matter yields (kg DM/ha) of legume herbage and significant effects from legume trials in Masvingo Province, Zimbabwe.

	Site (see Table 6)								
	2	3	4	6	7	8	9	10	11
SOIL CHARACTERISTICS									
pH ($CaCl_2$)	4.5	4.8	5.0	4.6	4.8	4.7	4.7	4.5	4.9
avail. P (ppm)	3	3	2	10	6	5	4	3	6
Ca (me/100g)	0.5	0.8	1.2	1.3	0.8	0.8	0.7	0.5	0.9
Mg (me/100g)	0.1	0.2	0.3	0.5	0.2	0.2	0.2	0.1	0.2
K (me/100g)	0.08	0.09	0.10	0.13	0.25	0.10	0.11	0.08	0.1
DM YIELDS									
Harvest date 1978	12/4	22/4	20/4	14/4	13/4	6/4	3/3	4/4	6/4
Townsville stylo									
no fertilizer	19	0	227	47	73	206	4	0	119
200 supers + lime	44	0	526	68	96	434	3	11	354
400 supers + lime	105	0	572	115	71	305	7	0	726
400 mix. + manure	33	10	411	171	104	311	5	15	530
Oxley stylo									
no fertilizer	473	84	349	494	272	1011	53	227	221
200 supers + lime	449	110	942	702	159	1841	399	452	328
400 supers + lime	847	306	[illegible]	1124	541	2017	604	184	268
400 mix. + manure	1054	59	886	929	312	1914	869	127	98
Siratro									
no fertilizer	289	131	1247	1840	696	1715	50	38	1501
200 supers + lime	832	578	2423	1993	1296	1912	466	340	1630
400 supers + lime	970	350	2087	1823	1390	1650	570	520	2092
400 mix. + manure	1254	625	3016	1948	1310	2155	797	920	1985
Archer									
no fertilizer	182	22	289	2544	709	2048	14	280	1314
200 supers + lime	430	450	904	2122	1283	2474	118	847	1336
400 supers + lime	857	806	1266	2049	1258	2458	366	836	1752
400 mix. + manure	1611	935	1178	2602	1404	2790	323	1654	1546
Sign. effects									
Legumes	***	***	***	***	***	***	***	***	***
Fertilizer	***	***	***			**	***	***	*
Interaction	**	*					*	**	*

For fetilizer treatments, see text.
* = P<0.05; ** = P<0.01; *** = P<0.001.

Source: Clatworthy (unpublished data)

introduction of legumes into the grazing areas as veld reinforcement or the setting up of strategic fodder banks in the arable areas would seem to be a necessary and manageable alternative.

Farmers were asked about their willingness to grow fodder legumes for animal feed and about factors that would affect their decision. One alternative presented to the farmers was to grow perennial shrubs as hedges or on contours, giving the necessary protection and fertilizer so that they could be cut-and-carried to the animals, usually after the crops had been harvested. Slightly more that half of the farmers in the sample expressed an interest provided certain conditions were met. Those not willing to grow them were less than a fifth of the total sample; the remainder of the sample group did not have ruminants.

The results in both Mangwende and Chibi were similar except that the Chibi farmers gave more weight to maintenance costs than to lack of knowledge as reasons for not growing them (Table 8).

The other alternative presented to farmers was to grow fodder on fallow land within the arable area, with the necessary protection, fertilizer and the requirement that the fodder be grown for at least 3 years. One-third of the households surveyed had fallow land, but the reasons for this were very different in Mangwende and Chibi. The proportions of farmers willing to grow fodder on fallow land were similar in the two areas (Table 9). Farmers generally demonstrated a reluctance to use arable land for fodder production largely due to a shortage of land.

DISCUSSION AND CONCLUSIONS

Farmers in communal areas are very aware of the role and importance of livestock in their farming systems and, furthermore, are aware that their grazing areas are being

Table 8. The main reasons given by farmers with grazing livestock for their willingness or unwillingness to grow perennial shrubs as hedges or on contours in Mangwende and Chibi Communal Areas.

	Mangwende	Chibi
Willing to grow, provided:	78%	82%
seeds or plants available or cheap	42%	48%
fertilizers provided or sufficient manure	22%	21%
fence or protection supplied	15%	13%
knowledge or help given	15%	8%
sufficient labour or land	5%	-
no condition	-	6%
other	1%	4%
TOTAL*	100%	100%
Unwilling to grow, due to:	22%	18%
Shortage of labour	39%	31%
land not protected	11%	23%
lack of knowledge	19%	-
costs of fertilizers/inputs	19%	8%
insufficient cattle	11%	15%
maintenance costs and others	11%	23%
TOTAL*	100%	100%

* To calculate sub-class percentages, a general index was calculated by assigning weightings of 1, 0.75 and 0.5 for the first, second or third reasons a particular farmer gave for his decision.

Source: FSRU Survey (1984).

Table 9. Proportion of farmers with grazing livestock with fallow land and reasons given by these farmers for their willingness or unwillingness to grow fodder on this land in Mangwnde and Chibi Communal Areas.

	Mangwende	Chibi
Proportion with fallow land, due to:	42%	47%
sufficient fertile land	31%	-
insufficient draught	23%	26%
insufficient labour	20%	3%
insufficient cash/inputs	17%	10%
fertility or weed problem	3%	16%
insufficient grazing for cattle	6%	-
lack of rain	-	45%
TOTAL*	100%	100%
Willing to grow, provided:	35%	40%
fertilizer provided or sufficient manure	41%	39%
seed available	19%	31%
fence or protection provided	22%	12%
sufficient land	12%	-
sufficient cash	3%	-
advice provided	3%	10%
sufficient draught power	-	3%
TOTAL*	100%	100%
Unwilling to grow, due to:	65%	60%
lack of land	46%	54%
shortage of labour	24%	16%
land not fenced	14%	8%
lack of knowledge	10%	-
insufficient cattle or grazing	2%	6%
priority to grain crops	-	16%
other	4%	-
TOTAL*	100%	100%

* To calculate sub-class percentages, a general index was calculated by assigning weightings of 1, 0.75 and 0.5 for the first, second or third reasons a particular farmer gave for this decision.

Source: FSRU Survey (1984)

conditions) that will improve their situation, particularly following the disastrous results of the last few years of drought.

The introduction of forage legumes into communal grazing areas or fallow land would seem to be practicable since it has been clearly shown that improved productivity would result. However, if the grazing areas are to be reinforced, some form of improved management with rotational grazing and reduced stocking rates will be necessary. Child labour for herding duties is now scarce, fencing is very expensive, particularly for subsistence farmers, and as there is already a critical shortage of draught power in communal areas, it is unlikely that stocking rates would be reduced by much. However, if watering points were to be strategically placed so that a better distribution of stock on the grazing areas could be achieved, this alternative has some promise.

There are legumes that have been shown to be well adapted and able to persist in higher rainfall areas such as Mangwende. More research is required to find other suitable legumes, particularly those with an erect growth habit. In lower rainfall areas such as Chibi, the range of legumes that could be used is much narrower and so greater efforts need to be made to find more suitable legumes for the harsh conditions found there. There appears to be a greater willingness to grow legume shrubs in hedgerows and along contours than on fallow land, and so there is a need for more research as there has been little work in this direction.

Lack of knowledge was a relatively important constraint on the adoption of growing legumes. If the staff in the Department of Agricultural Technical and Extension Services are able to give a clear demonstration to farmers in the Communal Areas of the benefits of growing and using legumes correctly, the farmers are likely to be much more willing to adopt the practice. Constraints with regard to inputs were another major consideration and initially the farmers should be provided with seed, starter fertilizers and some assistance with establishment and use of legumes until the benefits of using legumes are generally accepted.

Due to the critical need to improve grazing management and the importance of group decisions in the use of communal grazing resources, research is needed into the dynamics of group decision-making in order to identify appropriate administrative and organizational communal management alternatives. Communal responsibilities for improved grazing management must be successfully established before forage legumes can be effectively introduced to assist in sustaining livestock feed production. In addition, this will prevent the upsetting of crop production priorities, as it is from their cash crops that surpluses are produced. Thus the direct and indirect benefits of introducing forage legumes must be weighed against the direct cash and opportunity costs of the resources used.

One recent development that is being experimented with is to overhaul completely the planning of a whole communal area or at least an entire section of it. In Mweneze Ward of Matibi No.1 Communal Area this has meant the movement and consolidation of households into villages and arable lands to designated areas. The effect has been to release extra areas for grazing. Grazing schemes have been planned and will be implemented in these areas. Under these conditions, legumes should thrive and persist provided they are adapted and are managed properly and if adequate advice and inputs are given initially.

Milk is a valued commodity in communal areas and is in short supply. In order for the cow to produce enough milk for both the household and her calf, both the quantity and the quality of the cow's diet must be increased. This could be achieved by using legumes in a cut-and-carry system and would be a means of increasing the cash income of the farmers (Clatworthy, 1985).

Despite the unfavourable conditions for legumes in the communal grazing areas, there are places were sown legumes, notably *Cassia rotundifolia*, Townsville stylo and Oxley stylo, have established and spread. However, most of the sowings in communal farming areas have been on individual arable holdings, and many have been used for seed production followed by dry-season grazing. In an effort to foster this interest, the Grassland Society of Zimbabwe has, for the past two seasons, organised a competition in selected communal areas, with prizes awarded to farmers who have established plots of forage legumes and used them intelligently. Competitions are popular among the farmers and so this is another way of encouraging the use of new technologies within their farming systems.

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RESEARCH ON FORAGE LEGUMES IN SWAZILAND

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ABSTRACT

Livestock production in Africa is often limited by inadequate supplies of good quality forage. The importance of forage legumes in overcoming feed shortage has long been recognised in Swaziland judging by the amount of research that was carried out during the 1960s and 1970s. Many areas of legume management were explored during that period, including plant introduction and testing, N fixation, legume inoculation, legume nutrition and the introduction of legumes into native veld. While much was learnt from these studies, this paper emphasises the need to intensify research on other areas of legume management to minimise dependence on pure grass pastures, which require large quantities of costly fertilizer N for maximum output.

INTRODUCTION

Swaziland, bordered by the Republics of South Africa and Mozambique, is one of the smallest African countries, situated between the 25th and 27th parallels south of the equator. It has a total land area of 17,365 km^2, which is divided into four distinct topographical regions: the high-veld, middleveld, lowveld and lubombo, each running roughly north to south. Agriculture is the backbone of the country's economy, and current estimates put the livestock population at some 636,000 head of cattle, 320,300 goats, 31,800 sheep and 16,456 pigs (HTS, 1983).

The cattle are mainly Nguni, a local breed of the Sanga type. It is a dual-purpose animal, producing both meat and milk. Its milk production is estimated at between 400 and 500 litres per lactation, which is just sufficient to raise a calf. However, under good management and feeding it may produce an extra 250 litres which could be sold. Jerseys, Friesians, Canadian Holsteins, Simmentaler and other *Bos taurus* breeds are gaining popularity in both the highveld and middleveld where the climate is favourable. Crosses of these breeds with the Nguni are to be found scattered throughout the country. Although the cattle population is far higher than the human population, the demand for meat, milk and other livestock products still exceeds supply. Government efforts to achieve self sufficiency in these products are emphasised in the current 5-year development plan. Inadequate nutrition is recognised as the major constraint to introducing exotic breeds and on the productivity of the local Nguni.

Given the prevailing economic conditions, Swaziland will have to rely heavily on intensive use of pastures to improve the nutritional status of livestock. The cost of other feed sources are generally too high to be recommended for widespread use at current management levels. However, the productivity of both native pastures (or veld) and planted pastures is limited by nitrogen deficiency in most soils in the country. Moreover, many forage species grow very rapidly as soon as the rains commence in early summer (October). At this time leaf production is high and crude protein content and dry-matter digestibility are satisfactory. By the end of the wet season (March) the plants develop tall flowering stems which are low in protein and high in fibre. These conditions place severe restrictions on livestock production, particularly during the dry season, which can be as long as 7 months in a year.

In order to increase pasture productivity and quality significantly, the low N status of the soils could be supplemented either by applying fertilizer N or by growing forage legumes.

Due to the high input of fossil energy required for its manufacture, N fertilizer is generally expensive and this is reflected in its low consumption in Africa (IFDC, 1980). Moreover, current trends in global recession are likely to create further instability in the price and supply of N fertilizer. A cheaper and more effective way of increasing the N status of the soil would be to introduce legumes, which not only fix appreciable quantities of atmospheric N but also contain high levels of protein, minerals and vitamins. Furthermore, this high quality can be maintained over a long period and their inclusion in grass pastures may prolong the grazing season.

The importance of forage legumes has long been recognised in Swaziland judging by the amount of research that was carried out during the 1960s and 1970s. Although much of the work was not published, many areas of legume management were covered, examples of which are given below.

PLANT INTRODUCTIONS

Between 1959 and 1968 a programme of plant introduction and screening was carried out in the major ecological zones of Swaziland (Whitmarsh, 1975). A world collection of over 100 legume species and cultivars was established in nurseries located at Malkerns Research Station (moist middleveld), Luve (dry middleveld), Big Bend (lowveld) and Mangcongco (high-veld). All introductions were evaluated for productivity, seed yield, persistence and palatability. At the end of the 10-year period, the following species were scored as highly suitable for the different ecological zones:

Moist middleveld

Cajanus cajan
Desmodium discolor
Desmodium intortum
Desmodium sandwicense
Desmodium uncinatum

	Glycine javanica
	Leucaena javanica
	Trifolium repens
Dry middleveld	*Cajanus cajan*
	Desmodium discolor
	Desmodium intortum
	Leucaena leucocephala
Lowveld (under irrigation)	*Desmodium uncinatum*
	Glycine javanica
	Medicago sativa
Highveld	*Lolononis bainesii*
	Trifolium spp.

Later trials were generally based on these recommendations.

NITROGEN FIXATION UNDER SWAZILAND CONDITIONS

The beneficial effect of pasture legumes in maintaining or increasing the N status of soils in the temperate zone has long been established. Data collected from the temperate regions of Australia, Europe and the USA show that pasture legumes can fix up to 515 kg N/ha (Bryan, 1962). However, doubts have been expressed regarding the capacity of tropical legumes to fix N. From a number of experiments on the African continent, it was concluded that tropical legumes were unlikely to improve soil fertility and animal production (Anon., 1967), although these misgivings were later abandoned (Keya, 1977; Ayanaba, 1980). Several trials to investigate the ability of perennial tropical legumes to replace N fertilizers applied to pure grass pastures were established at Malkerns Research Station in the Swaziland middleveld. Some of the results are summarised in Table 1.

Table 1. Yields of grass pastures fertilized with 112 kg N/ha and unfertilized grass/legume mixtures, Malkerns Research Station, Swaziland, 1967/68 - 1972/73.

Species	Year						
	1967/68	68/69	69/70	70/71	71/72	72/73	**Mean**
Eragrostis/ Paspalum + N	4571	6730	6141	5003	5790	1045	4880
Eragrostis/Paspalum + *Desmodium*	3942	5535	2074	8919	1500	1018	3831
Kikuyu + N	3436	4467	3537	3944	7314	1744	4073
Kikuyu + *Desmodium* spp.	2689	1179	1642	2494	1164	769	1656
Stargrass + N	6424	6573	4358	4137	5522	3272	5047
Stargrass + *Desmodium*	2748	3153	2164	3211	1402	1140	2303

Source: Whitmarsh (1975).

It is clear from these trials that *Desmodium* spp. were unable to substitute adequately for fertilizer N. For example, Kikuyu grass + 112 kg N/ha yielded a 6-year mean yield of 4073 kg dry matter/ha, whereas Kikuyu + *Desmodium uncinatum* gave only 1656 kg/ha. Similarly, Stargrass + 112 kg N/ha gave a 6-year mean yield of 5047 kg dry matter/ha while Stargrass + desmodium gave only 2303 kg/ha. These results are disturbing when compared with figures from East and Central Africa. Trials in Uganda by Wendt (1970) showed that adequately fertilized pastures of *Stylosanthes guianensis* (=*S. gracilis*) could fix as much as 290 kg N/ha per year . At Kitale in Kenya, *Desmodium uncinatum* was shown to fix up to 178 kg N/ha per year (PRS, 1969). In Malawi, the inclusion of *Stylosanthes guianensis* and *Desmodium* *intortum* produced a dry-matter yield equivalent to that of a pure grass sward receiving 448 kg N/ha per year (Department of Agriculture, 1961).

The inability of the legumes to fix N under Swaziland condition may be attributed in part to the relatively short growing season typical of southern Africa. It would perhaps require several years before a response could be detected. Furthermore, Thomas (1973) pointed out that the poor performance of tropical legumes in some instances may not be due to any inherent inability to fix N but rather to a lack of understanding of their requirements for normal growth and development. Thus, if the true potential of legumes is to be fully realised it is essential to gain a knowledge of the environmental factors that may limit their growth, nodulation and N fixation. Some of these factors have been investigated in Swaziland.

INOCULATION OF LEGUME SEEDS

The presence or absence in the soil of the appropriate *Rhizobium* sp. determines whether or not inoculation of the legume seed is required. Those species or varieties that do not require inoculation have an obvious advantage in countries such as Swaziland where pasture improvement is being undertaken by small-scale farmers. In a review article, Thomas (1973) cited many instances of natural nodulation in *Stylosanthes* spp. However, he also observed that such symbioses may not necessarily be the most effective in fixing N, since there are wide variations in the effectiveness of rhizobium strains isolated from different sites. Inconclusive results were obtained from a short-term study conducted in Swaziland using inoculated stylo oversown in unimproved veld. The study comprised three cultivars of *Stylosanthes guianensis* together with *Stylosanthes hamata* and *S. humilis*. In one treatment the legumes were inoculated and coated with peat, Mo and P. In another, the legumes were not inoculated but coated with peat, Mo and P. The control plots received no treatment. Fresh herbage yields from two cuts are shown in Table 2.

Table 2. Effect of seed treatment on fresh-weight yields of *Stylosanthes* spp. cultivars from two cuts.

Legume	Seed treatment		
	Inoc/treat[1]	Uninoc/treat	Control
	--------- Fresh weight (t/ha) --------		
S. guianensis (Schofield)	7.1	7.1	7.1
S. guianensis (Endevour)	7.8	8.1	6.4
S. guianensis (Cook)	8.5	7.8	7.8
S. guianensis (Verano)	9.5	6.8	6.8
S. humilis (Townsville)	6.4	5.9	7.9
Mean	7.9	7.1	7.2
SE ± 0.94			

Source: Ministry of Agriculture and Cooperatives (1979).

1. Inoc. = inoculated with rhizobia
   Uninoc. = uninoculated
   treat. = peat coating + Mo + P.

Average yields were 7.9 t/ha for inoculated legumes, 7.1 t/ha for non-inoculated legumes and 7.2 t/ha for the control. Thus, inoculation of these *Stylosanthes* species did not give any obvious advantage. These results appear to indicate that under Swaziland conditions, stylosanthes may nodulate freely in the field without inoculation. Similar results have been reported for desmodium in Uganda (Wendt, 1971) and Kenya

(Keya and van Eijnatten, 1975). This could be confirmed by conducting a more comprehensive trial.

RESPONSE TO FERTILIZERS

Apart from the short-term need to modify the environment to give favourable conditions for the seedlings to establish, long-term modifications are also needed to enable legumes to thrive in competition with grasses. An experiment established in 1964 (I'ons, 1967) showed that lime was essential for the legume *Desmodium pilosiusculum* (=*D. sandwicense*) but that trace elements (Zn and Mo) produced no significant effects. In a later trial (I'ons, 1968), greenleaf desmodium and silverleaf desmodium were shown to respond to lime up to 500 kg lime/ha, higher rates depressing dry-matter yield. This low lime requirement of desmodium on a highly acid soil is in agreement with several Australian findings (Norris, 1966). In the same trial, applying up to 25 kg K/ha significantly increased the productivity of silverleaf desmodium. No further yield increment was recorded beyond 50 kg K/ha. The legumes did not respond to P. This is surprising because many crops have responded to P fertilizers on the red kaolinitic soils at Malkerns Research Station and research elsewhere has shown that *Desmodium* spp. should be no exception (Olsen and Moe, 1971). This finding appears to suggest that response of legumes to P in Swaziland is unlikely to be as spectacular as has been reported in other countries.

VELD IMPROVEMENT WITH LEGUMES

Small-plot trials in Swaziland have consistently shown that the introduction of legumes into native veld results in large increases in both the amount and quality of herbage produced. One can expect therefore that the carrying capacity will be increased and the performance of the animals enhanced as compared with animals grazing unimproved veld. This hypothesis was tested in one trial in which *Stylosanthes guianensis* + 20 kg P/ha was oversown on an unimproved veld in the moist middleveld. Table 3 shows the liveweight gains per unit area per year from 1966 to 1973.

Table 3. Mean liveweight gain (kg/ha per year) of cattle grazing unimproved veld and veld oversown with stylo, Swaziland middleveld, 1966/67 - 1972/73.

Year	Control	Stylo + P
1966/67	126.6	170.2
1967/68	128.8	182.6
1968/69	94.1	131.0
1969/70	97.4	173.6
1970/71	61.6	191.5
1971/72	134.4	224.0
1972/73	114.2	159.0

Source: University of Botswana, Lesotho and Swaziland (1975).

Although stocking rate was somewhat arbitrarily adjusted to conform with level of production in the paddocks, there was an increase in livestock performance from the use of stylo + P in every year of the trial. These results indicate that livestock productivity and the carrying capacity of the moist middleveld can be increased significantly by applying P and introducing stylo. It is unfortunate that the effects of P and the legume were not separated during the trial period.

INTRODUCTION OF LEGUMES INTO VELD THROUGH GRAZING ANIMALS

The need to keep pasture establishment and maintenance costs as low as possible has been a major consideration in Swaziland's research programmes, which are aimed largely at improving peasant agriculture. One study investigated the possibility of oversowing the veld with seed dropped in the faeces of cattle fed a meal containing legume seed. The use of such a method of seed establishment presupposes that the legume species used does not require inoculation, because it is assumed that rhizobia would not survive the ruminant digestive process and inoculation of seed would therefore be pointless. Presumably the inoculant would have to be introduced separately into the soil. Workers in New Zealand (Suckling, 1952) and Japan (Yamada et al, 1972) have succeeded in establishing legumes by this means, particularly those species that produce a large proportion of hard seed. Seed that is not hard or that has been scarified in mechanical harvesting is more likely to be digested by the animal.

In the trial in Swaziland, established in 1974 (Whitmarsh, 1975), steers were fed a weekly ration of 1.5 kg maize meal and 200 g of live seed of *Desmodium intortum* per animal. Unpublished data from the study indicated that the germination percentage and survival rate of desmodium were high enough to recommend this method of legume establishment for veld improvement in Swaziland.

RESEARCH ON TEMPERATE LEGUMES

Many temperate legumes, e.g. white clover and lucerne, have been grown successfully in the subtropics, although their reliability for year-round grazing has been questioned. The winter climate of Swaziland appears to be ideal for the production of temperate pasture species. Research has shown that a wide range of temperate legumes can be grown with irrigation during the winter, including lucerne, red clover, white clover, purple vetch and lupin. However, there are indications that in most cases the hot, subtropical summer conditions may be too severe to allow persistence of the temperate species (Whitmarsh, 1968). The effect of over-seeding established *Eragrostis curvula* pasture with white clover for irrigated winter grazing was studied in the middleveld (Whitmarsh, 1975). The hypothesis was that temperate legumes may stand a better chance of survival if grown in the partial shade of a tropical grass, provided that correct management is employed to ensure that competition from the grass is not too intense. In this region, most tropical grasses become dormant during winter, irrespective of water supply. Thus if it proves possible to maintain the legume throughout the summer, it may thrive on its own in winter with irrigation. As a result, tropical species could provide the main grazing in summer followed by temperate species in winter. This would allow the pasture to be used throughout the year. Moreover, the legume would provide extra N, which would benefit the grass in each succeeding summer. Unpublished yield data taken from the study clearly indicated the attractiveness of this strategy. In a small-scale dairy project at Malkerns (Whitmarsh, 1977) it was demonstrated that very high levels of milk production could be obtained throughout the year by combining tropical species such as Rhodes grass with a mixture of temperate species such as white clover and Italian ryegrass with irrigation in the winter time.

THE FUTURE OF FORAGE LEGUMES IN SWAZILAND

Research on forage legumes in Swaziland started in 1958 and an active programme was pursued until 1978. Reference has been made to some of these trials above. Since that time, only a few long-term trials have been maintained and most of these have now outlived their usefulness. From the initial period of active research much valuable information has been accumulated and the basic principles of veld and pasture management for local conditions are now well established. However, as the cost of N fertilizer continues to increase there is an urgent need to increase research on the potential of legume-based pastures. Any new programme of research will inevitably resolve itself into three basic activities:

1. Plant introduction and testing;
2. Legume nutrient requirements; and
3. Evaluation of management techniques.

Plant introduction and testing

Since 1953, when the first introduction nurseries were established, the legume species that grow best in the local environment have been determined. Any future work should be directed towards the selection of more productive cultivars within these species. Plant breeders throughout the world are constantly improving on the existing material and many of the improved lines have not been grown or tested in Swaziland. In addition to introduced cultivars, a collection of indigenous legumes will have to be built up for subsequent identification and testing.

Nutrient requirements of legumes

Much groundwork has already been done but, as pointed out earlier, some of the results were inconclusive, emphasising the need for further studies. Moreover, with improvement in management techniques, it is likely that nutrient requirements will change and new recommendations will have to be formulated.

Allied to legume nutrition will be the question of rhizobial activity and its contribution to the production of protein.

Evaluation of management techniques

Both irrigated and rainfed pastures may be planted as pure stands or as mixtures of grasses and legumes. The components of the mixture need not be planted at the same time. The seeds may be broadcast, drilled, sown under a companion crop or interplanted in an annual cash crop such as maize. More information is needed as to which combination of such factors is best in a given situation. Furthermore, a thorough knowledge of the growth curves of new cultivars will be necessary in order to put them to maximum use in extending the productive period of the pastures.

The success of such research will depend on cooperating with other institutions, reviewing world literature relevant to the research programme, visiting research institutions in neighbouring countries and building up a team of workers and technicians together with the necessary research equipment and facilities.

CONCLUSIONS

Apart from the limited research currently being carried out at the University of Swaziland (Ogwang, 1985), pasture research in Swaziland has been at a virtual standstill since 1978. A project on pasture improvement is soon to be started by the Ministry of Agriculture with the financial backing of the International Development Research Centre, Ottawa, Canada. This move should renew interest in forage legumes.

Although a vast amount of knowledge has been accumulated on forage legumes, their popularity has remained relatively low among Swazi stockowners. This may be attributed to problems of bloat and management, lack of persistence and poor hay-making qualities, as well as the availability of cheap N fertilizer from neighbouring countries in the past. The farmers can only be encouraged to adopt large-scale use of forage legumes through effective extension services. Simple technological packages can be easily adopted by the average stockowner while sophisticated systems may be tested first in the Government-sponsored Rural Development Areas.

Although legume-based pastures without N fertilization are likely to produce less forage than a pure grass pasture receiving high levels of N, the numerous advantages associated with legumes should make them a more attractive feed source in the coming years.

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REVIEW OF RESEARCH ON FORAGE LEGUMES IN SIERRA LEONE

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ABSTRACT

The paper reviews research on annual and tree/shrub forage legumes in Sierra Leone between 1982 and 1985. Research on annual forage legumes has focused on their nutritional value. General covered comprise *Centrosema, Pueraria, Stylosanthes, Mimosa* and *Calopogonium*. An inventory of tree legumes in Sierra Leone identified 69 accessions comprising 29 species, some of which have potential for use as forages, including *Acacia ataxacantha, A. fernesiana, A. nilotica, A. senegal, Afezelia africana, Albizia adiathifolia, A. lebbeck, A. zygia, Cajanus cajan, Cassia sueberriana, Gliricidia sepium* and *Leucaena leucocephala*.

FORAGE LEGUMES IN GHANA: REKINDLING INTEREST IN RESEARCH AND INTEGRATED MANAGEMENT

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ABSTRACT

The paper reviews information on livestock production and the influence of soils and vegetation on agriculture in Ghana. A large amount of information on forage legumes has been generated, especially between the 1940s and 1960s, but research has since lapsed. The use of crop residues of food legumes for feed has also been studied. The author concludes that integrated research is needed and that the information available should be applied at farm level.

ADVANCES IN PASTURE RESEARCH AND DEVELOPMENT IN ZAMBIA

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ABSTRACT

Cattle production is important in Zambia but productivity is low, due in part to the poor nutritive value of natural pastures, particularly in the dry season. Other constraints include poor management, high cost of inputs and low product prices. To improve the nutrition of the grazing animal, a research programme has been developed with emphasis on the integrated use of cultivated and flood-plain pastures. The major contributions of the legume were to prolong the period of liveweight again and to reduce or eliminate dry-season weight losses. Well-adapted pasture crops with high seed yield have been identified.

LEGUMINOUS FODDER TREES IN THE FARMING SYSTEM - AN OVERVIEW OF RESEARCH AT THE HUMID ZONE PROGRAMME OF ILCA IN SOUTHWESTERN NIGERIA

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ABSTRACT

The potential of leguminous fodder trees in farming systems of humid West Africa is considered in the light of research work carried out by the Humid Zone Programme of the International Livestock Centre for Africa (ILCA) at Ibadan, Nigeria. ILCA's agronomy research effort focuses on the leguminous species, *Leucaena leucocephala* and *Gliricidia sepium*. The paper reviews a variety of research trials ranging from the improvement of germplasm materials to the development of fodder production systems, and concludes with a recommendation for more research and development attention on the integration of fodder trees within exsisting farming systems.

INTRODUCTION

Trees are the dominant natural vegetation in most tropical ecosystems and should therefore be recognised as essential for stability in land-use systems in these areas (Nye and Greenland, 1960; Rachie, 1983). The tree component in these systems is necessary to protect the fragile tropical soils from the effects of torrential rainfall and scorching sunshine.

Traditional farming systems in the tropics have been known to rely on trees and shrubs for soil fertility mainterance and regeneration. The dominant farming system in these areas is based on the shifting cultivation and bush fallow concepts by which a piece of land is cropped for a period, usually 3-5 years, and then left fallow, commonly for 4-10 years, to allow the soil fertility to regenerate. Trees play a vital role in this process and leguminous trees, which are able to fix atmospheric N_2, have an added advantage over other trees in this respect. Judicious use of leguminous trees in the farming system can aid in the recycling of nutrients and water from deep in the soil, fix N, lower soil temperature, reduce soil evaporation, minimise leaching and run-off, provide shade for animals and crops, provide animal feeds and in some cases supply human food.

In the farming system these trees are capable of enhancing both crop production, through soil fertility maintenance, and livestock production, through increased availability of high quality feeds. The efficiency of this, however, depends on the species used and the manner of their integration and management within the cropping system.

The dominant ruminant livestock species in the humid zone are the trypanotolerant West African Dwarf sheep and goats. These animals are very widespread in the zone, especially in rural areas, where they are said to contribute 5-10% of total farm income of the mainly arable-crop-farmer population. Their management is generally sub-intensive and low-investment oriented and their integration into the farming system is loose. The potential exists, however, for an improvement in the integration of crop and livestock systems through cultivation of leguminous fodder trees within arable-crop farms. This potential has been the backbone of research of ILCA's Humid Zone Programme (HZP) based in Ibadan, Nigeria.

The objective of the HZP of ILCA has been to improve the overall productivity of the small farmer in the zone, through the development of improved livestock production technologies and their integration into the existing farming system. Improved feeding and disease control are the programme's major areas of activity. The former is met largely through research on leguminous browse production and utilisation, and is the central theme in this paper.

The choice of browse rather than grasses or herbaceous legumes was influenced by the dominant role that trees play in the tropical environment and also by their relative ease of integration into farming systems of the area. Browse trees also have the advantage of remaining productive during the critical dry season, when most grasses and legumes dry out.

ILCA's research aims at documenting how crops and soil fertility are affected by linking small ruminant production with cultivated fodder trees, and at developing production techniques that are relevant and workable for the small-scale farmer. In the context of this paper, and in the humid zone of West Africa generally, a "small farmer" usually has about 2-5 hectares of farmland, may own a few sheep and goats (usually 2-6 animals per farmer) and might also keep some poultry or pigs, all under sub-intensive management.

SPECIES SELECTION AND IMPROVEMENT

The choice of tree species for use in any intercropping system with arable crops is of utmost importance (Rachie, 1983), as it determines, to a large extent, the success or failure of the system. ILCA's choice of *Leucaena leucocephala* (Lam) de Wit and *Gliricidia sepium* (Jacq.) Steud. was influenced by the availability of information on the two species, and also by earlier research carried out on the two species at the International Institute of Tropical Agriculture (IITA).

In 1981 ILCA initiated a species screening trial of native leguminous trees, with the objective of identifying local alternatives to leucaena and gliricidia - both of which are exotic. Twenty-two native browse species were selected on the basis of their reported palatability, rapidity of initial growth, ability to coppice and dry season leaf retention, and screened with leucaena and gliricidia as control species. Some of the species screened were *Acacia albida, Afzelia africana, Albizia lebbeck, Antiaris africana, Azadirachta indica, Cassia siamea, Daniella oliveri, Ficus thonningii, Moringa oleifera* and *Parkia clappertoniana*.

After 2 years of observations, it was clear that none of the species could match the productivity of leucaena and gliricidia. This line of research was therefore suspended and research effort intensified on leucaena and gliricidia.

No basic research was thought necessary on leucaena because of the wealth of information already available on the species and the availability of improved leucaena germplasm lines. Gliricidia on the other hand was relatively unknown, unstudied, and unimproved. A major gap was therefore apparent - the lack of any systematic effort to improve gliricidia germplasm.

GLIRICIDIA GERMPLASM COLLECTION AND EVALUATION

In March 1983, ILCA embarked on joint collection trip with CATIE (Centro Agronomico Technico de Investigation y Ensenenza), to Turialba, Costa Rica, in Central America, believed to be the origin of the species. Forty-seven accessions of gliricidia were collected which are being evaluated for productivity, under a frequent pruning regime similar to that used in alley farming, with the "Ibadan Local" gliricidia as control. Considerable variation in vigour and productivity has been detected over six harvests made so far. A number of lines have been found to be superior to "Ibadan Local" though the yield of latter was near the overall mean yield at each harvest (ILCA, 1984). The four highest-yielding accessions have shown a high degree of stability by consistently out-yielding "Ibadan Local" by 20 - 32% in the last four harvests (Table 1). In April 1984, seed from these four lines were sown in a bulk "high yield population" plot for multiplication. Bulk harvest of seed from this orchard will give a "synthetic" or a "blend," depending on whether gliricidia proves to be cross- or self-

Table 1. Mulch DM yields of gliricidia at different planting densities.

Spacing (cm)	Trees/m row		Mulch yields (t/ha)						
			1984				1985		
	Expected	Realised	12/4	21/5	17/8	3/10	4/4	14/5	Total
4	25.0	15.8	0.86	1.03	2.01	0.61	0.69	1.18	6.38
8	12.5	9.6	0.72	1.01	2.39	0.66	1.07	1.45	7.30
16	6.2	4.7	0.49	0.73	1.67	0.51	0.90	1.18	5.48
25	4.0	3.4	0.59	0.77	1.82	0.58	0.89	1.22	5.87
33	2.0	2.7	0.54	0.75	1.74	0.58	0.92	1.14	5.67
50	2.0	1.8	0.36	0.54	1.31	0.48	0.81	1.03	4.53
50 (stake)	2.0	2.0	2.74	1.26	3.21	0.61	1.14	1.37	10.33
LSD (P=0.05)		-	0.38	0.25	0.54	NS	NS	NS	-
CV(%)	-	-	30.4	19.2	18.3	21.5	20.0	29.7	-

pollinated. This approach of combining accessions was adopted to minimise the need for seed production in isolated blocks while hopefully producing populations with high yield potential and sufficient genetic diversity for wide adaptation within the tropics.

The programme's germplasm collection and evaluation work also includes a recently initiated evaluation of gliricidia germplasm collected in Central America and Mexico by the Commonwealth Forestry Institute (CFI), Oxford, U.K. This evaluation is being done in eight West African countries under a network sponsored by the International Development Research Centre (IDRC).

ESTABLISHMENT OF GLIRICIDIA

Traditionally, gliricidia is established from stakes, and all of ILCA's early work with this species was with stake establishment. In 1982, however, it became apparent from ILCA's on-farm research that this method of establishment could seriously hinder the adoption and spread of any technologies developed with the species. There was therefore the need for research on flowering, seed production and propagation of gliricidia from seed.

Research in this direction, initiated in November 1982, showed a wide range of variation in flowering, fruiting and seed production (Table 2). The effective flowering and fruiting period for gliricidia was observed to be from November to March. The single variable most closely related with seed yield per tree was the number of set racemes per tree. Earlier flowering trees produced and set more racemes, and thus yielded more seed (Sumberg, 1985).

Gliricidia pods are linearly dehiscent and seeds are dispersed from pods on drying. In seed collection, it is therefore necessary that pods are picked green on maturity, before drying commences. Such pods could then be sun dried, with a wire mesh covering to prevent excessive seed scattering.

Table 2. Flowering and seed production variables among 20 sample gliricidia trees, Ibadan, Nigeria.

Variable	Range	Mean[a]	Coefficient of variation (%)
Total racemes/tree	16 - 633	311.8	66.9
Set racemes/tree	0 - 219	73.8	86.9
Percentage raceme set	0 - 46.4	21.7	53.8
Buds/raceme	18.2 - 40.1	25.9	20.0
Pods/raceme	1.0 - 2.0	1.2	18.1
Percentage pod set	4.2 - 8.6	5.7	22.8
Seeds/pod	2.9 - 5.3	4.2	16.0
Number of seeds/tree	0 - 1442	420.3	95.9
Seed yield/tree (g)	0 - 89	24.6	93.0
Days to maturity	37 - 45	40.6	7.6
Branch fresh weight/tree (g)	5.5 - 18	10.4	30.7

a. Includes only trees which set pods, n=18.
Source: Sumberg (1985).

Seed propagation trials with seed collected this way and seed harvested dry from parent trees showed no significant differences in germination and seedling vigour, thus establishing that seeds could be effectively collected from fresh green pods and sun-dried for seed propagation purposes. Trials are currently in progress to study the storage potential (longevity) of such seeds under different storage conditions.

Gliricidia planting density

With the successful propagation of gliricidia from seed, all subsequent work with the species was with seed establishment. It therefore became necessary to establish the optimum spacing for seed-established gliricidia and to compare productivities of seed- and stake-established gliricidia at their optimum densities.

A trial with six intra-row spacing treatments ranging from 4 to 50 cm (seed establishment) plus a 50 cm spacing stake-established gliricidia as control was established in a randomised complete block design at Ibadan in May 1983. Plots were single rows, 5 m long, and spaced 4 m apart. Trees were established with two maize crops each year from 1983 to 1985. The first tree cutting (harvesting) was made in April 1984; as at May 1985, six harvests had been made.

Up-to-date results, summarised in Table 3, indicate that stake-established gliricidia at 50 cm spacing was more productive than all spacings of seed-established gliricidia in the initial harvests. Stakes are clearly able to sprout and establish faster than seeds, which require a long period of seedling establishment during which the seedlings are sensitive to weed competition.

The superior productivity of the stake plants was, however, completely eroded by the fourth harvest as the seeded trees increased their productivity with each harvest. In general, mulch yield in seeded trees increased with increasing tree density. Eight centimetre spacing of seeded trees, which gave approximately 10 established trees per metre row (25,000 trees/ha) is emerging as the most competitive of the seed-establishment spacings tested (Figure 1).

This trend is expected to continue with more of the seeded trees increasing in productivity in subsequent harvests and out-yielding the stake-established trees, especially during the dry season. The major reason for this expectation is the development in seeded trees of a more prominent tap-root system, which is capable of tapping water and probably nutrients from deeper soil layers. It has been observed that stake-established trees have shallow root development.

Table 3. Fresh mulch yields from *Gliricidia sepium* germplasm evaluation.

	Harvest date						
	20/10	13/4	1/6	6/9	7/12	10/4	Total
	Yield (t/ha)						
Overall mean	8.2	6.6	7.2	13.2	8.9	3.8	47.9
"Ibadan local"	7.2	6.1	7.6	13.2	8.9	5.2	48.9
	(100)	(100)	(100)	(100)	(100)	(100)	(100)
4 "high" yielding	10.7	11.1	9.0	15.9	11.3	6.5	64.5
accessions	(149)	(182)	(118)	(120)	(127)	(125)	(132)
Range	4.5- 11.9	3.8- 11.7	4.9- 9.2	8.7- 17.0	5.6- 12.7	1.8- 8.0	-
LSD(P=0.05)	3.1	3.3	3.8	4.4	3.8	NS	-
CV(%)	18.7	24.5	12.6	16.4	21.3	44.0	-

Values in parentheses indicate yield expressed as a percentage of "Ibadan Local" yield.

FODDER TREE CULTIVATION SYSTEMS

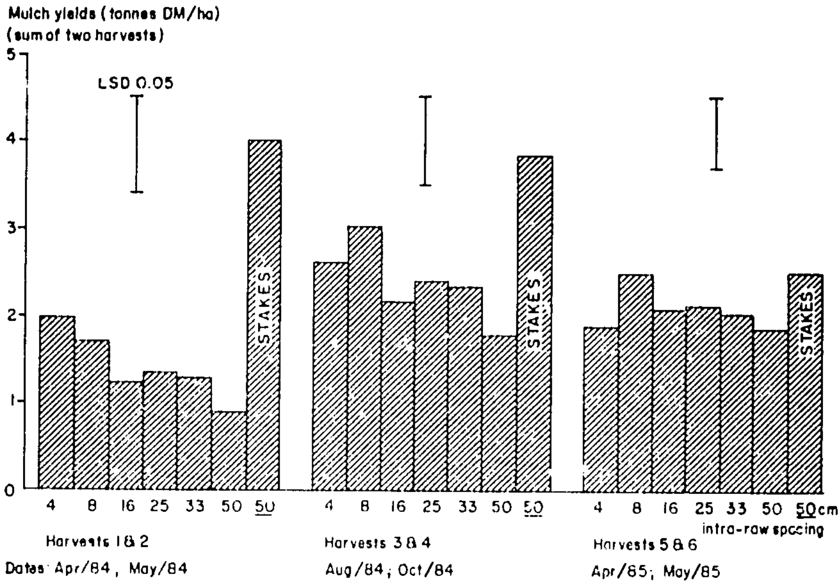
Three main points need to be taken into consideration in the development of fodder production strategies for small ruminant farmers in the humid tropics. These are:-

i) The overwhelming importance and dominance of crops relative to livestock in the zone.

ii) The fact that small ruminants, the major ruminant livestock species in the zone, are kept mainly by arable and tree-crop farmers, usually as a minor farm enterprise.

iii) Management of small ruminant production is generally sub-intensive, with minimal investments in feeding, housing and health.

Figure 1. *Effect of planting density (intra-row spacing) on mulch productivity of seed-established Gliricidia sepium.*



These three factors together dictate that fodder production systems for improvement of small ruminant production in the zone should be low-investment oriented and should not impinge unduly on land and/or labour required for the production of the farmers' primary product - arable crops. ILCA's approach to fodder intervention in the farming system places emphasis on integration of leguminous fodder trees in food-crop farms, as a means of linking small ruminant production with arable-crop production. Use of the trees for fencing and as shade trees, as well as for the establishment of feed gardens on small plots in and around compounds is also encouraged. The main production systems that ILCA is developing are alley farming, grazed fallow and the intensive feed garden (IFG) systems.

Alley farming has its roots in the alley cropping concept (Kang et al, 1981) of the International Institute of Tropical Agriculture (IITA), and is a system of cultivation in which food crops are grown between rows of leguminous fodder trees. The trees in the system are managed to produce both N-rich green manure for soil fertility maintenance and high-protein feed for small ruminants.

The grazed fallow is an off-shoot of the alley farming system and involves the grazing of fallow alleys in the periods when no crop is carried on alley farms. Such situations might range from short dry-season fallows to precise grazing rotations within alley farming. This system, which is also refered to as "alley grazing," permits even more integration of crop and livestock production, since manure is returned to the soil with potential soil fertility implications. However, it demands a higher level of management and might require extra investment. In this regard it is seen as a system with potential for the future. A number of on-going trials at Ibadan are giving useful indications of the parameters involved in linking alley farming and grazing. One such project is described in some detail in the following section of this paper. A detailed analysis of both alley farming and grazed fallow systems is given in a paper by Sumberg (1984).

THE ALLEY CROPPING/GRAZING ROTATION TRIAL

This long-term trial, conducted in cooperation with the Farming Systems Program (FSP) of IITA, occupies a key position in ILCA's alley farming research and development effort. The primary objective is to determine the effects of grazing natural pasture under fodder trees (alley fallow) over short periods (2 years) on soil fertility and subsequent crop yields. In addition, the trial provides some preliminary observations on animal performance within the alley grazing system.

The five treatments in the trial are:

i) Continuous cropping without trees;
ii) Continuous cropping in leucaena alleys;
iii) 2-year grazing/2-year cropping rotation in leucaena alleys;

iv) 2-year cropping/2-year grazing rotation in leucaena alleys;

v) Continuous grazing in leucaena alleys.

Treatments were arranged in a randomised complete block design with six replications. Alleys between rows of leucaena measured 4 m, and plots were 12 m x 10 m. The trial was started in May 1982 with the establishment of leucaena (treatments ii-iv) in an unfertilized uniform crop of maize. Two crops of maize have been planted in the trial each year since 1983. Except for the second season crops of 1984 and 1985, all cropping treatments received a basal dose of 30-45 kg N/ha and also received the same level of management. Leucaena trees within alley-cropped plots are pruned to a height of 50 cm, 2 or 3 times each cropping season and the entire foliage used as mulch.

In the grazing plots, the trees were cut once a year in 1983 and 1984. Cutting frequency in these plots is currently twice yearly, to minimise canopy closure and undergrowth shading of the "natural pasture" in alleys. The grazing plots are rotationally grazed for 2-day periods with stocking rates ranging from two to six sheep/plot (corresponding to 14-42 sheep/ha) depending on season and age group of grazing animals.

Yields of leucaena prunings

Prunings, in this paper, refers to the harvested foliage and branches that go back to the soil as mulch. When trees are pruned immediately following the dry season, foilage is stripped from the main stems and applied as mulch; stems are removed from the plots, and do not constitute a part of the prunings. In subsequent cuttings, both foliage and young stems and branches are applied as mulch, and constitute 'prunings'. Table 4 shows the productivity of the trees in the alley cropping plots from 1983 to first season 1985.

Table 4. Dry-matter yields of leucaena mulch in alley cropping plots.

	1983			1984			1985
Treatments	FS[1]	SS[2]	Total	FS	SS	Total	FS
	Tonnes dry mulch/ha						
2	2.56	2.78	5.34	4.03	2.15	6.18	5.34
3[3]	-	-	-	-	-	-	7.17
4	3.00	3.22	6.22	4.35	2.22	6.57	-
Mean	2.78	3.00	5.78	4.19	2.19	6.38	6.57
LSD (P=0.05)	NS	NS	-	NS	NS	-	7.50*
CV(%)	15	12	-	15	12.5	-	18

1. FS - First season
2. SS - Second season
3. This was a grazing treatment until FS 1985
* Significant at P = 0.05

From two or three mulch applications per crop, the trees provided approximately 4.5 and 2.6 tonnes of dry mulch per hectare in the first and second season respectively. In situations in which three prunings were carried out, the third is believed to contribute little or nothing to the crop , which would be in the late maturity stage at the time of the pruning. On an annual basis the trees yielded a mean of 6 tonnes/ha in the first 2 years after establishment.

The prunings applied to the maize crops contributed a mean of 115 and 62 kg N/ha to the first and second season crop, respectively (Table 5). This represents a significant N input, especially in areas where the use of inorganic N fertilizer is uncommon. It has been estimated, however, that only about 30-40% of the N in leucaena mulch is available to the maize crop (Guevarra, 1976).

Table 5. Nitrogen content of leucaena prunings[1] applied as mulch alley cropping plots.

Treatments	1983 FS[2]	1983 SS[3]	1983 Total	1984 FS	1984 SS	1984 Total	1985 FS
	kg N/ha						
Continuous alley cropping	88.9	66.7	155.6	106.3	53.6	159.9	106.1
Alley grazing/ cropping	-	-	-	-	-	-	165.2
Alley cropping/ grazing	105.8	72.2	178.0	118.2	54.3	172.5	-
Mean	97.4	69.5	166.8	112.3	54.0	166.2	135.7

1. Only 2 prunings/crop considered.
2. FS - First season.
3. SS - Second season.

Crop yields

The 1983 second season crop was lost due to drought. Maize/cowpea intercrop was substituted for sole maize in all plots in the second season of 1984. Crop yields from 1983 to first season 1985 are given in Table 6. In 1983 the alley-cropped plots yielded an average of 0.36 tonnes/ha (16%) more than the continous maize (no tree) plots. In the first season of 1984 the leucaena inputs of mulch and N contributed a peak 40% increase in maize yield compared to non-alley-cropping plots. This yield advantage was maintained, but reduced to 17% in the second season crop, which was intercropped with cowpea.

The response of the intercropped cowpea to the alley cropping situation appeared to be negative, as the non-alley-cropping yield was significantly greater than the mean yield

Table 6. Maize and cowpea yields in alley cropping trial.

	FS-1983	FS-1984	SS-1984		FS-1985
Treatment	Maize	Maize	Maize	Cowpea	Maize
Continuous crop.	2.19	2.55	1.16	0.66	2.49
Cont. alley crop.	2.54	3.75	1.45	0.49	2.83
Alley grazing/crop.	-	-	-	-	3.88
Alley crop./grazing	2.56	3.43	1.27	0.45	-
Ave. cont. crop.	2.19(100)	2.55(100)	1.16(100)	0.66(100)	2.49(100)
Ave. alley crop.	2.55(116)	3.5[illegible](14[illegible])	1.3[illegible](117)	0.47(71.2)	[illegible]
LSD (P= 0.05)	NS	0.92	NS	0.15	0.37
CV (%)	25.3	22.0	25.6	21.5	24.5

Values in parentheses indicate yield expressed as percentage of non-alley-cropping yield.

in the alley cropping plots. This negative response has also been observed in work done by the Farming Systems Program of IITA (Kang, personal communication), and probably indicated that cowpea, being a legume, does not require the extra N made available through alley cropping. Excess N is known to increase vegetative growth rather than grain yield in grain legumes. Compared with maize, cowpea probably also suffers more from competition for light and other factors in alley cropping on account of its morphology relative to the hedgerows (even when pruned). The maize/cowpea intercropping situation in alley cropping will be repeated during the second season of 1985 for further observation.

The cropping/grazing rotation came into effect in 1985 as plots under Treatment 4, which had been under alley cropping for 2 years (1983-84), were put to grazing in February 1985. Treatment 3 plots which were under grazing during the period were alley cropped with maize in April 1985. All plots received 45 kg N/ha during this season. Maize yield during this first season of the rotation is shown in Table 6. The yield obtained from the continuous alley cropping plot fell from 3.75 t/ha in first season 1984 to 2.83 tonnes, and was only about 14% over that obtained from the control (non-alley-cropping) plot. The alley grazing/cropping plot however yielded 3.88 t/ha, exceeding production under continuous cropping and continuous alley cropping by 56 and 37% respectively.

Effect on soil

The effect of the various treatments under study on soil chemical properties is only briefly mentioned in this paper. Changes in soil parameters are expected to develop over a number of years. However, it appears from preliminary data obtained that the alley cropping and alley grazing plots tend to be higher in organic C and total N than the non-alley-cropping plots (Table 7). This probably explains the observed yield response for maize. Other major nutrients such as K and P have so far not shown consistent trends, and are being continuously monitored.

Alley grazing

The 'limitations' of this trial, such as the size of unit plots (120 m^2) and the inter-row spacing (4.0 m for alley cropping) do not allow a thorough study of the alley grazing system. However, some indication of the problems and potentials were observed during the study which were consistent with earlier observations made in a preliminary study of alley grazing (Sumberg, 1985).

Initial stocking rates (May 1983 - August 1984) were 14 and 28 sheep/ha for the dry and rainy season respectively. At the onset of the dry season in September 1984, the first group of grazing animals, which consisted mainly of mature ewes, was replaced by a fresh batch of weaners to enable growth responses to be more adequately expressed. Overall

Table 7. Organic carbon and total nitrogen content of soil on three sampling dates.

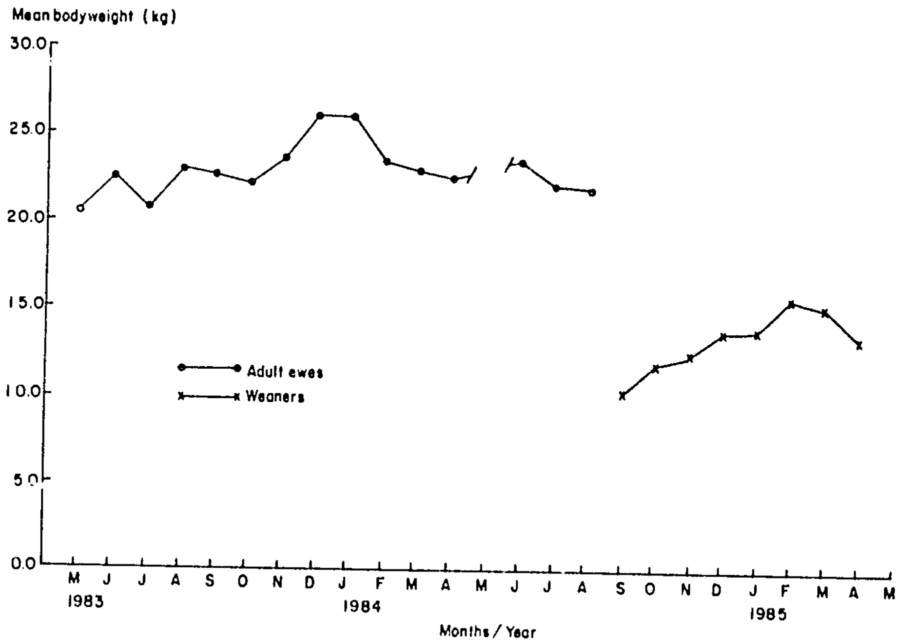
Treatment	Sampling date 15/5/82	31/8/83	15/8/84
		Organic carbon (%)	
Sole maize (no trees)	1.09 (100)[1]	1.27 (100)	1.09 (100)
Alley cropping	1.13 (104)	1.42 (112)	1.05 (96)
Alley grazing	1.29 (118)	1.50 (118)	1.19 (109)
		Total nitrogen (%)	
Sole maize	0.155 (100)	0.132 (100)	0.122 (100)
Alley cropping	0.161 (104)	0.148 (112)	0.129 (106)
Alley grazing	0.164 (106)	0.154 (117)	0.137 (112)

1. Figures in parentheses indicate organic carbon and total nitrogen content of the soils as a percentage of contents in sole maize plots.

stocking rate has been 26 sheep/ha since this period. The average bodyweights of the grazing sheep are shown in Figure 2. The observed trends for both groups of animals indicate a gradual rise in bodyweight through the dry season, which drops at the onset of the rains in March/April. It therefore appears that the environmental and probably disease stress of the rainy season is of far greater consequence than the diminishing ground vegetation of the dry season.

Another problem encountered in the system was the tendency of the sheep to debark the trees. This behaviour is suspected to be linked to the inadequacy of feed, as it is more intensive during the dry season. The alley cropping hedgerow spacing of 4 m also appears to be too close for a grazing system, especially if stockpiling of browse is intended for the dry season. An 8 m spacing would prevent

Figure 2. *Mean bodyweight of sheep grazing natural pasture in Leucaena alleys.*



canopy closure, and allow more light to the undergrowth pasture and the animals. Obviously the alley grazing system presents a lot of unanswered questions and more research is needed in its development.

The intensive feed garden (IFG)

This is a relatively new concept which is currently receiving a lot of research attention at ILCA. The IFG aims at intensive cultivation of fodder trees and grasses on a small plot of land, usually close to the farmer's animal holding area. It is especially suitable for situations where alley farming may be inappropriate for one reason or the other, and can also be used, in some cases, to supplement feed resources from alley farms.

The prototype IFG contains the legumes leucaena and gliricidia on one half and the grasses *Panicum maximum* and

Pennisetum purpureum on the other. The gardens are 200 m^2 and predicated on intensive nutrient cycling through the application of manure or fertilizer to maximise feed production from a limited area. The goal is to have gardens which will provide the major feed requirements for 4-6 animals.

Current research aims at further intensifying the gardens through modifications in spacing and design (spatial arrangement of trees and grasses), as well as quantification of their productivities and carrying capacities.

Animal response to browse supplementation

ILCA's research on fodder cultivation and management is backed by a series of controlled nutrition trials to determine the value of browse supplementation to the productivity of the animals. In general, small ruminants, especially goats, utilise browse more than cattle. The strong preference of small ruminants for leguminous browse - leucaena and gliricidia - is immediately evident when the animals are offered a mixed diet of browse and grasses or household scraps such as cassava peels. One farmer in ILCA's on-farm project site complained that his goats no longer accept cassava peels since he introduced them to leucaena.

Results from one ILCA study have shown that supplementation of leguminous browse to sheep and goats increases daily feed intake (ILCA, 1983). Similar results have been reported by Ademosun et al (1984) using leucaena and gliricidia in separate trials as supplements to panicum hay. The same authors also reported a linear relationship between the amount of legume fed and digestibility, dry-matter intake and digestible dry matter.

In another ILCA on-station trial to determine the effect of supplementation on long-term animal productivity, different levels of supplementation are being tested on West African Dwarf sheep (Table 8). Animals received one of four diets, irrespective of physiological condition, throughout

Table 8. Dietary regimes for West African Dwarf sheep in browse supplementation trial.

Regime	Basal[a] diet	Supplementary[b] browse (g DM/day)
1	*Ad libitum*	0 g DM/day
2	*Ad libitum*	200
3	*Ad libitum*	400
4	*Ad libitum*	800

a. Basal diet - *Panicum maximum*.

b. Browse - 50% *Leucaena leucocephala* and 50% *Gliricidia sepium*.

the period. Chopped *Panicum maximum* was available *ad libitum* to all animals, together with water and mineral lick. Preliminary results of the first 2 years of the trial are summarised in Table 9. Overall lambing interval was 239 days, ranging from 262 days on the control diet (basal diet, no browse supplementation) to 226 days at supplementation level of 400 g browse DM/day. Birthweight of lambs and dam weight before birth were 1.68 and 25.5 kg, respectively, with no significant effect of dietary regime.

Mortality rates of lambs decreased as the level of supplementation increased, with twin lambs improving from 0.43 on the basal diet to 0.25 at the highest level of supplementation. Lambs on the basal diet gained 64.4 g/day compared with 83.8 g/day for those receiving 800 g of browse daily.

These preliminary results give some indication of the potential of leguminous browse for improving small ruminant productivity through improved feeding. However, in order to improve the correlation between level of supplementation and performance, animals have been penned individually rather than in groups, and synchronisation of oestrus has been effected, so that all offspring should be born over a short

Table 9. The effects of browse supplementation on the productivity of West African Dwarf sheep. (Mean ±SE).

Observations	1	2	3	4	Mean
Parturition interval (days)	262 ±13.5	228 ±19.1	226 ±8.4	241 ±8.9	239 ±8.4
Litter size	1.26 ±0.087	1.27 ±0.089	1.19 ±0.082	1.17 ±0.078	1.22 ±0.04
Survival to 90 days	0.65	0.52	0.65	0.82	0.65
Birth weight (kg)	1.80 ±0.069	1.61 ±0.104	1.52 ±0.073	1.72 ±0.067	1.68 ±0.04
Daily liveweight gain to 90 days (g)	64.4 ±2.98	60.3 ±3.51	73.4 ±4.98	83.8 ±3.69	70.5 ±2.14

time. This will minimise variations in physiological stress among animals in the trial.

The basal diet on offer in the experiment has been found to be inferior to the diet of free-ranging village animals, when judged from growth rates. To achieve a growth rate of 74 g/day as reported for village sheep up to 90 days of (Mack, 1983) would require the basal diet of panicum to be supplemented with around 400 g of browse DM/day. However, the addition of high quality leucaena and gliricidia as a supplement to a village diet is expected to increase productivity. Efforts are currently being made to set-up a browse supplementation trial with free-ranging animals within the village to provide an accurate response of village animals to browse supplementation.

CONCLUSIONS

The potential of leguminous fodder trees within the farming

farming systems. Leguminous fodder trees can be used for the improvement of both crop and livestock production and thus offer a means of linking small ruminant production with arable crop production.

Both leucaena and gliricidia are highly productive, contain significant amounts of N (about 4% N; 20% protein) and establish well under tropical environments. They are therefore immensely suitable for the improvement of farming systems through soil fertility maintenance (for crop production) and increased availability of high-protein feed for small ruminants. Generally, the inclusion of leguminous trees in tropical land-use systems offers many advantages at minimum expense. Increased research and development attention in this area is therefore strongly recommended.

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FORAGE LEGUME-CEREAL SYSTEMS: IMPROVEMENT OF SOIL FERTILITY AND AGRICULTURAL PRODUCTION WITH SPECIAL REFERENCE TO SUB-SAHARAN AFRICA

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ABSTRACT

Intercropping forage legumes with cereals offers a potential for increasing forage and, consequently, livestock production in sub-Saharan Africa. But in such a system the yield depression of the cereal grain should be minimal, possibly not more than 15%, for it to be acceptable to the farmer.

The time of sowing of cereal and legume is critical for the yield of each crop. Data so far available indicate that undersowing within 10 days of planting a fast-growing cereal such as maize does not depress cereal grain yield significantly, but with slow-growing, long-season crops such as photosensitive sorghum, grain yield is greatly depressed. In the case of sorghum, high grain yield is obtained if the legume is sown 3 - 4 weeks after the cereal.

Intercropping forage legumes and cereals generally results in higher fodder protein yield than cereal alone. However, fairly high yields of legumes are needed to augment the cereal residues in order to produce a feed composition capable of meeting the basal nutritional requirements of ruminants.

The effects of intercropping on soil fertility varies with management practice. It is estimated that legume roots contribute between 5 and 15 kg N/ha to soil N under intercropping.

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INTRODUCTION

Agricultural output in the 1970s in sub-Saharan Africa (SSA) decreased by 1.3% while population rose by 2.7% (Meerman and Cochrane, 1982). They observed that yields are lower in SSA than elsewhere (Table 1). Among causes of declining productivity in SSA are the traditional system of shifting cultivation, very limited use of manures and fertilizers and the expansion of agriculture into marginal lands.

Table 1 Comparative yields of basic food crops in sub-Saharan Africa and other developing countries, 1969-71 and 1977-79. (Reference: 1961-63 yields = 100).

Crop	Sub-Saharan Africa 1969-71	Sub-Saharan Africa 1977-79	Developing countries 1969-71	Developing countries 1977-79
Millet	98	94	109	108
Sorghum	92	93	115	151
Rice	108	114	113	129
Maize	114	109	115	126
Roots and Tubers	117	117	129	129

Source: Meerman and Cochrane (1982).

Among the solutions being advocated to reverse the declining productivity are the introduction of cropping systems that conserve moisture and soil fertility and the close integration of livestock and arable farming (Pratt and de Haan, 1979; Bouldin et al, 1980; Oram, 1981). Okigbo (1984) observed that increasing agricultural output in SSA will require improved cropping systems, which will necessitate the integration of traditional and modern technologies as farmers are more likely to adopt modifications to existing farming systems than completely new ones.

Nitrogen deficiency is a major cause of declining soil fertility and poor quality forage. FAO (1983) noted that the major constraint to increased animal production is malnutrition caused either by overstocking or by low protein forage. Nitrogen is required in large quantities by crops and it is also the most expensive nutrient to manufacture since it is tied to escalating energy costs. Substitution of chemically produced N either wholly or partly could help to alleviate these problems.

This paper examines the potential of forage legume-cereal intercrops in enhancing soil fertility and increasing crop and livestock production in SSA. The socio-economic aspects of the problem are not included in the discussion.

INTER/RELAY CROPPING SYSTEMS

Extent of intercropping in sub-Saharan Africa

Intercropping is defined as the growing of two or more crops simultaneously on the same field (Andrews and Kassam, 1976; Sanchez, 1976). The most common form of cropping pattern in SSA is mixed intercropping, the growing of two or more crops simultaneously with no distinct pattern. Other types of intercropping are row, strip and relay cropping. Edje (1979) reported that a survey in Malawi showed 94% of cultivated land was planted to mixtures. Norman (1967; 1974) found that only 17% of the total cultivated land area in Zaria province of northern Nigeria was under sole cropping. Okigbo and Greenland (1976) examined the characteristics of cropping systems in traditional farming practices in tropical Africa and concluded that the most widespread cropping system consisted of mixed intercropping on compound farms. They also found that relay intercropping was more common than sequential cropping. Most of the legume-cereal intercropping involves grain legumes. The extent of forage legumes in mixtures is not known but is probably very small.

Advantages of forage legume-cereal intercrops

The call for integration of forage legumes with livestock has been accompanied by the suggestion that the key to increased livestock production in SSA lies in intercropping forage legumes and cereals (Gryseels and Anderson 1983). This is because of the heavy reliance of livestock on crop residues during the long dry season. The advantages that have been advanced for such an intercropping system are: (i) the possibility of N accretion from the legume to the cereal, (ii) maintenance of continuity of feed supply during the dry season, (iii) more efficient utilisation of low-quality cereals through the addition of high-protein forages, (iv) return of manure from livestock to the field, (v) increased crop productivity and (vi) greater dependability of return compared sole cropping.

FORAGE LEGUMES IN CEREAL SYSTEMS

Improvement of companion crop

Transfer of nitrogen: In a situation in which the farmer uses little or no fertilizer and the soil is very low in organic matter, the issue of transfer of N from legume to cereal assumes great importance. Two types of beneficial effects have generally been reported: higher N content and/or higher grain yield of the intercropped cereal in comparison with the cereal alone without any added N. While several investigators (Henzell and Vallis 1977; Whitney, 1977; Haystead and Lowe 1977) have found no evidence that the presence of a cereal or grass has a specific effect on the release of N from actively growing roots, other workers (Simpson 1976; Skerman, 1977; Eaglesham, 1980; Reynolds, 1982) have reported higher N contents and uptake in mixtures compared with sole-crop systems.

Most of the experiments involving exudation of N from legume roots have been conducted in pots. Under reduced light in the greenhouse, evidence has been obtained for considerable exudation (Black, 1968; Willey, 1979). However, shading may have a completely different effect in the field. Where legumes are continously shaded their overall capacity to fix N is likely to be impaired since growth and photosynthesis will be limited.

Field estimates of N accretion could be indirectly deduced if it could be shown that a cereal crop contains more N where it is associated with a legume than when it is grown alone without N fertilization. It appears that tropical forage legumes differ markedly in their ability to benefit associated cereals that have approximately the same growing period. In a comparative study with various legumes, Agboola and Fayemi (1972) reported an increase in maize grain yield over the control when *Phaseolus aureaus* (mungbean) was interplanted with the maize. The transfer of N from the legume to the maize was equivalent to 45 kg N/ha. Calopo and cowpea did not have similar effect. In an experiment at Debre Zeit, Ethiopia, Nnadi and Haque (1986) found higher N content in grain from maize that was intercropped with vetch whereas lablab and clover showed no such effect.

Competition for soil nitrogen: Pasture legumes are weak competitors for soil N if grown with grasses (Walker et al, 1956; Henzell and Vallis, 1977). If this finding can be extrapolated to cereals, then it follows that in a soil which is deficient in N the cereal crop will absorb most of the mineral N. This will compel the legume to fix more N than in a situation in which it is growing alone, provided other factors, such as light and water, are not limiting.

Fertilizer response

A large portion of SSA is situated in belts of uncertain rainfall in which there is uncertain response to N fertilizer. The primary aim here should be to maximise biological N fixation by utilising suitable legumes. However, since legume growth and consequently the amount of N fixed is affected by other nutrients there is also the need to examine the response of intercrops especially to P which has been reported to be widely deficient in SSA (Jones and Wild, 1975; Le Mare, 1984; Haque et al, 1985). Unfortunately only a few experiments have analytical data on nutrient composition and uptake.

Nutrient composition: Gardner and Boundy (1983) observed that N, P and Mn contents of wheat intercropped with lupins were significantly higher than those of wheat grown alone. The P and N contents of lupins were unaffected by intercropping (Table 2). Shelton and Humphreys (1975c) reported that intercropping upland rice (*Oryza sativa*) with stylo (*S. guianensis*) had no effect on the N content of the rice but significantly reduced its P content.

Table 2. Effect of intercropping on the N, P and Mn contents of wheat and lupins.

Cropping system	N %	P %	Mn ppm
Wheat alone	0.79	0.13	90
Wheat intercropped	0.86	0.15	150
Significance (F Test)	0.01	0.04	0.001
Lupin alone	2.35	0.14	7370
Lupin intercropped	2.35	0.14	6070
Significance (F Test)	NS	NS	0.001

Source: Gardner and Boundy (1983).

Haque (1984) found that the N content of lablab in intercrops with sorghum or maize was lower than in the legume crop grown alone. There was not much difference between the N values of pure and intercropped cereals.

Grain and stover yield: The general experience in intercropping experiments is that the grain and stover yields of a given crop in the mixture are less than the yields of the same crop grown alone, but that the total productivity per unit of land is usually greater for mixtures than for sole crops. Shelton and Humphreys (1975c) reported that yield of upland rice was 12% less when intercropped with *S. guianensis* than when grain alone. Gardner and Boundy (1983) also observed yield depression of cereal by lupins. Similar trends have been observed in the intercrops of *Dolichos lablab* with maize and sorghum at Debre Zeit, Ethiopia (Haque, 1984). The combined yield of the intercrops gave varying Land Equivalent Ratios (LER) ranging from 0.81 to 1.07 for sorghum and 0.86 to 1.07 for maize, depending upon the planting geometry (Table 3). Chetty (1983), in a review of work done over a 10-year period in India, noted little depression of the yield of finger millet by fodder legumes, field beans, *Dolichos lablab* and lucerne (Table 4).

In general, applying fertilizer N to fodder legume-cereal intercrops has been found to decrease the yields of the legume and to increase the yield of the cereal (Humphreys, 1978; Venkateswarlu, 1984).

Protein yield: Protein yield per hectare is increased by intercropping cereals and forage legumes. Waghmare and Singh (1984a) reported that the protein yield of sorghum was higher when intercropped with fodder cowpea than with grain legumes grown to maturity (Table 5). Intercropping stylo with sorghum has also given higher quality fodder (Mohamed-Saleem, 1984a). Haque (1984) showed that very high crude protein yields can be obtained from intercropping sorghum or maize with lablab. Highest crude protein yields were obtained from treatments in which two rows of sorghum and one row of lablab were planted, but with maize the highest protein yields occurred where cereal and legume were mixed and then broadcast (Figures 1 and 2). It is interesting to note that at maturity the crude protein yield of maize stover was higher than those of the intercrops. Generally the amount of

Table 3. Effect of intercropping lablab on grain yield (kg/ha) of sorghum and maize at Debre Zeit, Ethiopia, 1984.

Cropping systems		Sorghum	Maize
S_1	Cereal (pure)	1891	2032
S_2	Cereal/lablab (1:1)	-	-
	Cereal	1031	1563
	lablab	362	400
	Total	1393	1963
S_3	Cereal/lablab (2:1)	-	-
	Cereal	1191	1448
	Lablab	327	446
	Total	1518	1894
S_4	Cereal/Lablab (between normal	-	-
	rows) Cereal	1340	1408
	Lablab	247	378
	Total	1587	1786
S_5	Cereal/Lablab (broadcast)	-	-
	Cereal	1193	1556
	Lablab	266	400
	Total	1459	1956
	Lablab (pure)	737	516

Source: Haque (1984)

Table 4. Effect of intercropping finger millet with fodder crops on finger millet yield, Bangalore, India. (Row ratio 7:1).

Cropping system	Year	Rainfall (mm)	Yield (t/ha)	
			Millet	Intercrop
Finger millet + field bean	1978	565	2.69	-
			2.01	2.62
Finger millet + dolichos	1978	627	2.69	-
			2.54	2.69
	1979	850	1.22	-
			1.15	1.24
	1980	270	1.75	-
			1.70	1.60
Finger millet + lucerne	1978	426	2.69	-
			2.49	7.10
	1980	270	1.57	1.10

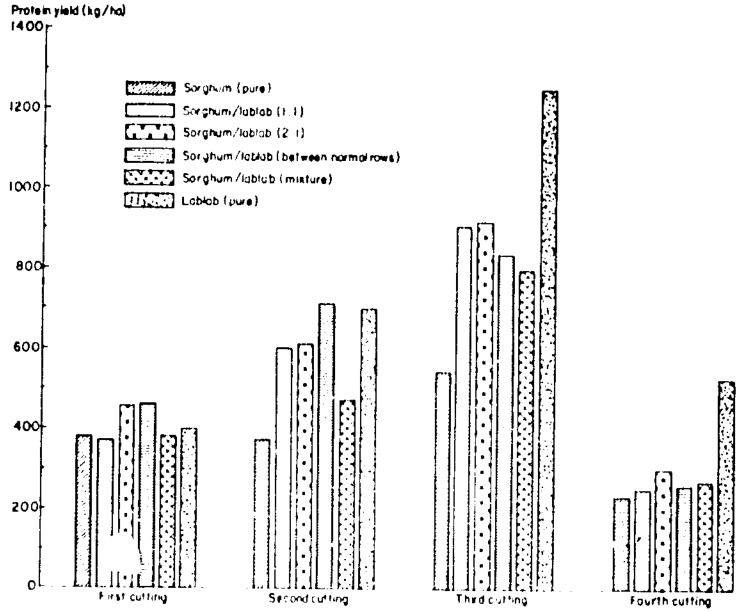
Source: Chetty (1983)

Table 5. Effect of intercropping on grain and stover yields (t/ha) and N uptake (kg/ha) of sorghum.

Intercropping system	Grain yield (t/ha)		Stover yield (t/ha)		N uptake (kg/ha)	
	1978	1979	1978	1979	1978	1979
Sorghum	3.09	3.44	6.50	6.95	52.6	53.1
Sorghum + greengram	3.32	3.71	6.80	7.84	76.6	90.1
Sorghum + groundnut	3.29	3.25	6.60	7.12	82.5	94.6
Sorghum + grain cowpea	3.25	3.73	6.95	7.69	86.9	89.6
Sorghum + forage cowpea	3.79	4.09	7.62	7.94	136.0	123.6
Sorghum + soyabean	3.15	3.55	6.70	7.24	77.2	78.3
SED	0.11	0.12	0.50	0.27		

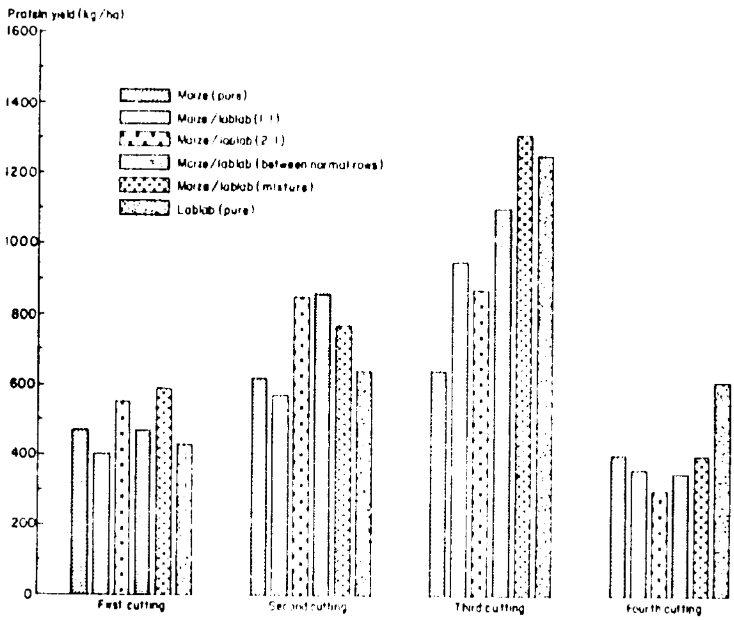
Source: Waghmare and Singh (1984a)

Figure 1. *Fodder crude protein yields of sorghum/lablab intercrops at various growth stages.*



Source: Hoque (1984)

Figure 2. *Fodder crude protein yields of maize/lablab intercrops at various growth stages*



Source: Hoque (1984)

crude protein in the system decreases with increasing time lag between the sowing of cereal and legume (Kanyama and Edje, 1976; Mohamed-Saleem, 1984b). Table 6 shows that the decrease in crude protein yield with time is attributable to low legume yield.

Table 6. Effects of sowing date of stylo on grain, stover and crudeprotein yields of maize and on dry-matter and crude-protein yield of stylo.

Treatment	Grain yield	Stover yield	Crude protein
	---------- Maize (t/ha) --------		
Pure maize	10.02	14.66	0.44
Undersown with stylo at 5 DAP	9.65	13.19	0.49
Undersown with stylo at 4 WAP	10.24	14.07	0.41
Undersown with stylo at 8 WAP	10.15	14.37	0.42
SE	NS	NS	NS
	---------- Stylo (kg/ha) ------		
Pure stylo		2380	255
Undersown at 5 DAP		154	16
Undersown at 4 WAP		20	1.1
SE		1.5	0.2

DAP = days after planting; WAP = weeks after planting.
Source: Kanyama and Edje (1976).

IMPROVEMENT OF FEED QUALITY

Qualitative improvement of cereal residue

If a cereal-forage legume intercrop is to increase livestock production the yield of legumes should be high. Ruminant animals can synthesise most amino acids if the N supply is adequate. Therefore, protein quality is not of major importance to animals grazing pasture or feeding on crop residue. The most important factor is crude protein content. For maintenance, the N content of the feed ingested should be at least 1.1% (Humphreys, 1978). To meet even this minimum level requires that the yield of legume be quite high.

Suppose a sorghum crop yields 5 tonnes of stover per hectare and contains 0.35% N, while the stylo intercrop contains 2.5% N. The amount of stylo needed to attain the minimum N for basal metabolism (1.1%) may be calculated as follows: Let the amount of stylo in kg/ha be Y, then

$$(5000 \times 0.35\%) + (Y \times 2.5\%) = (5000 + Y)\ (1.1\%)$$

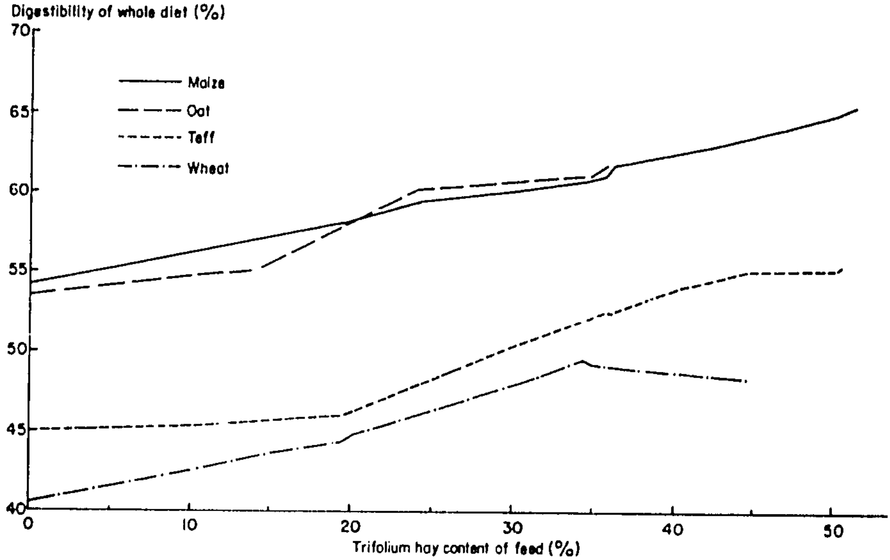
Solving the equation for Y gives 2679 kg. Therefore we need to produce more than 2.5 t of stylo per hectare to meet the N requirement. The amount of legume required will decrease if its N content is high and will increase as the protein content of the feed is raised.

Voluntary intake and digestibility of rations of cereal residues and legume hay

Nutritive values of cereal crop residues can be increased by chemical methods such as treatment with alkalis or the addition of molasses and urea but such methods are generally out of reach of the small farmer. Addition of legume haulms to cereal crop residues has been shown to increase the voluntary intake or the digestibility of the ration.

Mosi and Butterworth (1985a) found that the addition of 20-25% of *Trifolium tembense* hay to teff (*Eragrostis tef*) straw increased feed intake of sheep by 20-30%. In another study, Mosi and Butterworth (1985b) reported that addition of *Trifolium tembense* hay to teff, oat, wheat and maize straw significantly reduced the consumption of each straw but significantly increased total consumption of dry matter. Increases were also obtained in the apparent digestibility of dry matter, crude protein and P of each mixed diet when compared with each cereal residue alone (Figure 3).

Figure 3. *Effect of addition of Trifolium tembense hay on digestibility of cereal straws.*



Source: Mosi and Butterworth (1985b)

Studies in Sudan show that supplementation of berseem (*Medicago sativa*) and *Sorghum vulgare* with molasses significantly increased the digestibility of *S. vulgare* by Sudan zebu cattle and desert sheep but had no effect on the dry-matter digestibiility of berseem (Ahmed and Ahmed, 1983). Butterworth et al (1985) also reported that legume supplements increased the intake and digestibility of rations based on cereal crop residues. They found that the dry-matter intake of wheat straw was 41 g/kg $LW^{0.75}$ compared with 60 g/kg $LW^{0.75}$ for *Trifolium tembense* hay. The apparent digestibility coefficients of dry matter were 42 and 51% for wheat straw and legume hay, respectively. Thus, if adequate amounts of legume hays can be produced, the nutrition of ruminants will be greatly improved. The increase in digestibility of cereal residue produced will depend on the amount of legume haulms produced under a given intercrop system.

ENHANCEMENT OF SOIL FERTILITY

A third aspect of forage legume-cereal intercropping is the maintenance of soil fertility under continuous cultivation. In order to maintain soil fertility under continuous cultivation in SSA, the soil N content will need to be increased. This may involve modification of the traditional cropping system so that it still satisfies the economic need of the farmer while at the same time improving the nutrient status of the soil. The extent to which intercropping a cereal with a forage legume can enhance soil fertility will be evaluated in this section. We shall examine the practice of 'cut-and-carry', in which the tops of both cereals and legumes are removed from the field where they were grown and either fed to livestock or used for other purposes. Where the crop residues are fed to livestock the manure may not necessarily be returned to the same farm.

Dinitrogen fixation

For a legume to attain its potential for biological N fixation the symbiosis between the plant and the *Rhizobium* must be working properly. In particular, the manufacture of carbohydrates in the leaves and their downward translocation to the nodules must be adequate. The quantity of N fixed is very largely dependent on the dry-matter yield of the plant, which in turn is a reflection of the legume genotype and the environmental conditions during growth (Jones, 1977; App et al, 1980). While no data are available on nodulation and N_2 fixation by forage legumes in cereal intercrops, a few studies have been carried out in grain legume-cereal systems. Reddy and Willey (1980) reported that groundnut had fewer nodules and much lower N_2 fixation per plant in a millet-groundnut mixture than when grown alone. Nambiar et al (1983) also found similar effects with respect to nodulation but N_2 fixation was only slightly reduced in a maize-groundnut intercrop with no N applied (Table 7). Graham and

Table 7. Effect of intercropping and nitrogen fertilizer (kg/ha) application on nodulation and nitrogen fixation of groundnuts.

	Nodules /plant	Nodule wt. mg/plant	N_2 fixation umoles C_2H_4 /plant per hour
Sole groundnut	171	124	21.1
Groundnut + maize: No N	160	117	20.2
N_{50}	165	93	9.4
N_{100}	150	78	7.0
N_{150}	134	65	3.5
SE	15.4	11	1.9

Source: Nambiar et al (1983)

Chatel (1983) reported the planting bush bean in an intercrop with maize increased early nodule development by markedly inhibiting N_2 fixation after flowering. On the other hand, Nair et al (1979) observed better nodulation of cowpea intercropped with maize, especially when cowpea was planted between rows of maize, while soya bean and pigeon_ea showed reduced nodulation in intercrops (Table 8).

If N_2 fixation and nodulation are significantly reduced in intercrops this would mean a greater demand on soil N by both legume and cereal.

Nitrogen content of roots

A few estimates have been made of the amount of N in forage legume roots in pure legume stands. Henzell (1981) reported a range of 15-111 kg N/ha in temperate legume roots. The amount left in roots appeared not to be related to the total N fixed but rather was genetically determined. Burton (1976) found that 50% of the total N in *Trifolium pratense* cv. Ken Star was in the roots but for other legumes the value was

Table 8. Effect of intercropping on nodulation of legumes at various nitrogen levels.

Cropping system	N applied (kg/ha)				
	0	40	60	120	Mean
	Nodules/plant				
Cowpea (pure)	16	23	21	17	19
Cowpea in maize (inter-row)	25	29	33	30	29
Cowpea in maize (intra-row)	19	20	20	17	19
Soyabean (pure)	33	39	48	37	39
Soyabean in maize (inter-row)	24	39	50	26	35
Soyabean in maize (intra-row)	25	30	39	31	31
Pigeon pea (pure)	15	25	19	21	20
Pigeon pea in maize (inter-row)	13	18	24	18	18
Pigeon pea in maize (intra-row)	15	24	17	17	18
Mean	21	27	30	24	

Source: Nair et al (1979)

between 12 and 20%. Estimates of root N in tropical environments are a bit lower than those reported for temperate regions. Musa and Burhan (1974) reported a range of 16-22 kg N/ha for legumes grown in the Gezira, Sudan. These workers also cited the work of Oke (1967), who found that *Calopogonium mucunoides* and *Pueraria phaseoloides* retained 10 and 20%, respectively, of plant N in the root system in a Nigerian soil. Also Whiteman (1971) reported that 20 and 29% of the N fixed by *Desmodium uncinatum* and *Phaseolus atropurpureus*, respectively, in Australia was retained in the root system (Table 9).

It appears that in monocrops the average amount of N from the root system will range from 20 to 50 kg N/ha. Instantaneous sampling of roots may in some instances lead to

Table 9. Amount of nitrogen in sole-crop legume roots and tops grown for forage.

Legume	Tops	Roots	Total	Root N as % of total
	------	kg N/ha	-------	
Lupinus angustifolius cv Frost[a]	383	47	430	10.9
Trifolium incarnatum cv. chief[a]	211	15	226	6.6
T. pratense cv. Ken star[a]	175	111	286	38.8
T. repense cv. SI[a]	209	46	255	18.0
T. subterraneum cv. Mt. Barker[a]	199	48	247	19.4
I. vesiculosum cv. Meechee[a]	253	38	291	13.1
Vicia hirsuta[a]	326	69	395	17.5
Phaseolus trilobus Ait (Phillipesara)[b]	203	16	219	7.3
Clitoria ternata (Clitoria)[b]	185	22	207	10.6
Dolichos lablab L. (Lubia)[b]	181	18	199	9.0
Arachis hypogaea L.[b]	193	17	210	8.1
Desmodium uncinatum[c]	86	35	121	28.9
Phaseolus atropurpureus[c]	121	30	151	19.9

Sources: [a] Henzell (1981), [b] Musa and Burhan (1974), [c] Whiteman (1971)

underestimation of root contribution to soil N. This could happen in cases where nodules are continually shed and new ones grown. Musa and Burhan (1974) observed some variability in nodule persistence. Nodules of *Dolichos lablab, Vigna unguiculata* and *Phaseolus trilobus* Ait were reported to be weakly attached to roots and were shed following cutting but groundnuts had permanent nodules. The question that needs to be addressed is how much root N is available under intercropping.

Mineralisation of nitrogen in legume roots

The rate of mineralisation of N in legume roots is a function of the N content of the roots, which varies considerably between legumes (Nnadi and Balasubramanian, 1978). Roots with an N content of 2% or more are likely to mineralise fast. Henzell and Vallis (1977) cited Bartholomew's (1965) figure of 60% decomposition of legume residue in the first year and 10% per annum for the remainder. Since the yield of legume haulms in intercrops is about 25% of the sole-crop potential one would expect a corresponding decrease in the root system. Thus, assuming 25% of the 20-50 kg N/ha average of sole crop legume roots is found in mixtures, this is equivalent approximately to 5-12 kg N/ha. If 60% of this is mineralised in the first year it will yield about 3 to 7 kg N to a subsequent crop.

Residual effects

The contribution of N by a forage legume to a subsequent crop is less controversial than current transfer of N. It is generally agreed that some quantity of N will result from root and nodule decay (Henzell and Vallis 1977). The amount of N left in the soil will depend on the type of intercropping practised, since each method has a different effect on growth of the legume and consequently, on the amount of N fixed. Waghmare and Singh (1984b) in India reported that the N requirement of a non-legume crop can be considerably reduced after intercropped fodder legume (Table 10). This large residual effect does not agree with the earlier discussion on the contribution of legume roots to soil N. However, it is not clear whether the presence of legume roots could increase mineralisation of cereal roots and native soil organic matter by decreasing the overall C/N ratio. Such an effect could explain the results Waghmare and Singh (1984b) and others. The data of Nair et al (1979) are more within the range of yield increases expected from residual effects of intercropped legumes.

Table 10. Grain yield of wheat in relation to preceding intercrops.

Treatment	Wheat grain yield (t/ha)		
	1978	1979	Mean
Sole sorghum	3.40	3.61	3.51
Sorghum + green gram	4.05	3.75	3.90
Sorghum + groundnuts	4.33	4.01	4.17
Sorghum + grain cowpea	4.30	4.03	4.17
Sorghum + fodder cowpea	4.69	4.11	4.40
Sorghum + Soyabean	3.61	3.47	3.54

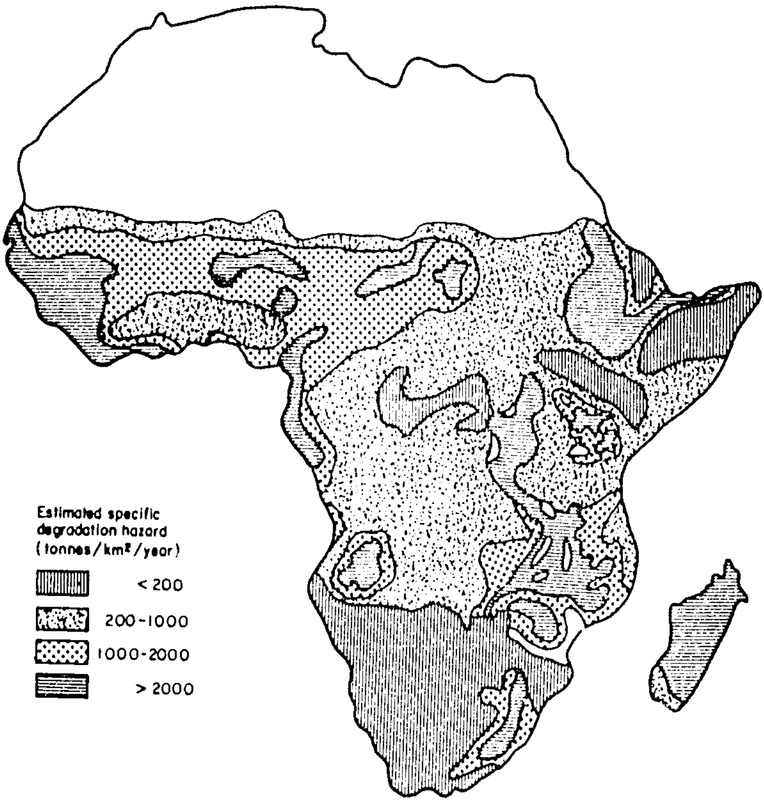
Source: Waghmare and Singh (1984b)

Though studies of the residual effects of forage legumes are usually focused on their N contribution, there may also be other benefits. Williams and David (1976, cited by Graham and Chatel (1983), reported that subterranean clover increased available P and organic-matter levels and rendered Zn, Fe, Cu, and Mn more available. The advantage of such effects on associated cereals is obvious.

Erosion control

Jones and Wild (1975) suggested that erosion might be low under subsistence agriculture because of the predominant practice of intercropping and semi-sequential or relay cropping. However, as cropping intensity increases, the risk of soil erosion increases especially in marginal lands. Recent estimates of erosion hazards in Africa put soil losses at very high rates, e.g. Allen (1980) estimated that losses in Ethiopia amounted to nearly 1000 million tonnes per year. Soil erosion has been identified as a serious problem on Alfisols in West Africa. These soils are characterised by unstable structure that forms a crust when exposed to raindrop impact (Lal, 1980). Estimated soil losses in sub-Saharan Africa are shown in Figure 4.

Figure 4. *Fournier's rainfall erosion hazard classes within Africa south of the Sahara (modified).*



Source El-Swaify and Dangler (1982)

Soil loss under intercropping has been shown to be less than under monocropping (Aina et al, 1977). Runoff and soil erosion have been found to be proportional to the time required for full canopy to develop (Aina et al 1977), hence the use of fast-growing forage legume crops which produce early ground cover is beneficial for the protection of the soil.

Green manuring in intercrops

Although green manuring is an age-old practice in Asia (Singh and Das, 1984) it is hardly used in SSA. The problems associated with the use of green manures have been dicussed by Jones and Wild (1975) and Nicholaides et al (1984). The major drawbacks are the high labour requirement for incorporation and the loss of one season required to produce the green manure. These problems could be minimised by planting a fast-growing forage legume between rows of widely spaced (about 90 cm) long-duration crops. The green manure can be hoed up and allowed to decompose *in situ*. The technique of greenleaf manuring is crucial in alley cropping and has been shown to yield 75, 2.9 and 2.6 kg of N, P and K/ha per year respectively (Singh and Das, 1984) and well over 100 kg N/ha per year (Kang and Duguma, 1984).

COMPETITION IN FORAGE LEGUME-CEREAL SYSTEMS

Light

The individual yields of forage legumes and companion crops are generaly lower in intercropping experiments than in monocrops. The decrease in biomass production has been attributed to competition for light, moisture and nutrients. Several workers (Willey, 1979; Reddy and Willey, 1979; Baker and Yusuf, 1976) considered light to be the most important factor in competition, particularly when the crops are of different durations.

More efficient use of light can also be attained by careful spatial arrangements of multi-storey cropping with tall and short crops, provided the short crops are adapted to low light intensities. Light also has an important effect on the reproduction of some species. Jones and McCown (1983) reported that Caribbean stylo (*Stylosanthes hamata* cv. Verano) produced little seed in an intercrop with maize due to its failure to flower in the shade of a full maize canopy

(50,000 plants/ha in 75 cm rows), whereas *Alysicarpus vaginalis* produced 2000-4000 seeds/m^2.

Nutrients and soil moisture

According to Kurtz et al (1952), below-ground competition is mostly limited to competition for moisture and mobile nutrients such as nitrate. Competition for immobile nutrients, such as P, does not normally occur except in limited regions where the root systems of the intercrops are in actual contact. The use of a forage legume that can fix large amounts of N would reduce one of the major sources of competition.

In the semi-arid areas or in relatively dry years in the humid region, competition for water can be severe. Thus Kurtz et al (1952) observed that, in a season when moisture was limiting, yield of maize intercropped with alfalfa and ladino clover was greatly reduced even with adequate N fertilization. Growing crops with different rooting patterns, and which thus exploit different soil layers, would reduce competition for water and nutrients.

Different views have been expressed regarding the relative importance of above- and below-ground competition (Reddy and Willey, 1979; Snaydon and Harris, 1979). Conflicts could be resolved by examining resource utilisation at different fertility levels in greater detail.

Minimising competition in forage legume-cereal mixtures

Farmers will tolerate only small reductions in the grain yield of cereal crops due to intercropping with forage crops, since cereal grain is the first priority of the farmer. A decrease of 10-15% relative to the cereal monocrop may be acceptable to the subsistence farmer. Some agronomic practices that can help minimise competition and increase the productivity of intercrops are discussed below.

Time of sowing: The time of sowing is critical for optimal production of cereal grain and forage. The best time depends on the cereal and the legume in question and needs to be determined experimentally. Mohamed-Saleem (1984a) found that planting *Stylosanthes guianensis* cv. Cook or *S. hamata* cv. Verano on the same day as an unimproved sorghum variety reduced grain yield by over 70%, but the reduction was less if the legume was sown 3 weeks after the cereal. In another trial, it was observed that an improved, medium-duration sorghum cultivar, SK 5912, sown on the same day as *Centrosema pascuorum, Alysicarpus vaginalis* and *Macroptilium lathyroides* did not suffer significant yield reductions.

Kanyama and Edje (1976) in Malawi reported only 4% decrease in grain yield of maize when *Stylosanthes guianensis* cv. Schofield was sown 5 days after the cereal (Table 6). Delaying the sowing of the legume increased maize yield but drastically reduced the yield of the legume. Thomas and Bennett (1975a), working in Malawi, observed that undersowing maize with a mixture of Rhodes grass and silverleaf desmodium (*Desmodium uncinatum*) after the first weeding of the maize reduced grain yield by 6.5%. Experiments in northeast Thailand with rice have shown that undersowing a medium-duration variety gave little or no difference whether the rice was undersown simultaneously or 10 days later (Shelton and Humphreys, 1975b).

The indication from the few time-of-planting studies is that sowing a forage legume simultaneously with a fast-growing cereal has no effect on cereal yield, but more work is required with different crop species. Large-seeded legumes, such as lablab, which germinate fast are likely to compete more with cereals if sown at same time than small-seeded ones such as *Trifolium* and *Medicago* species.

Planting pattern: Apart from the time of sowing, it may also be necessary to manipulate planting patterns in order to maintain cereal yields. An approach that appears promising involves leaving two cereal stands per hill at wide spacing (0.3 m) and planting the intercrop legume on alternate rows.

This system allows the cereal to be maintained at or near the optimum monocrop population and, if necessary, a third intercrop to be plantd between the sorghum hills. Using the above technique, Mohamed-Saleem (1984a) found that inter-row sowing of *Stylosanthes guianensis* reduced grain yield by about 10% compared with pure sorghum plots.

Where fields are ridged, furrows are normally not planted. This need not be the case. Thomas and Bennett (1975b) compared broadcasting forage seeds with drilling on ridges or in furrows. They found that drilling a mixture of silverleaf desmodium and Rhodes grass on ridges or in furrows after the first weeding of maize produced maize yields similar to those achieved when the same amount of forage seeds was broadcast, but gave significantly higher legume dry-matter yields (Table 11). Drilling in the furrow has the advantage that a hand-operated planter can be used.

Table 11. Effect of different metnods of undersowing silverleaf desmodium on yields of intercrops.

Treatment	Maize Grain	Maize Stover	Legume stover
	----------	(kg/ha)	----------
Maize only	2891	5699	-
Legume drilled on top of ridge	2799	5464	577
Legume drilled in furrow	2666	5254	559
Legume broadcast	2869	5524	370

a. Legume undersown 3 weeks after maize.
Source: Thomas and Bennett (1975b)

Ridging can accelerate water erosion if the ridges are not on the contours, and planting forages in furrows would help check such erosion hazards.

Planting density: In cereal-forage intercrops it is important that the population of the cereal crop be as close as possible to its maximum monocrop population, and the density of the forage legume should not be so high as to substantially decrease grain yield. At high density (81 plants/m^2), stylo substantially reduced the grain yield of the rice intercrop (Shelton and Humphreys, 1975a). Similar effect of high lupin rates on wheat yields have been observed by Gardner and Boundy (1983).

CONCLUSIONS AND RESEARCH NEEDS

This review shows that very little work has been done on forage legume-cereal mixtures in sub-Saharan Africa or indeed elsewhere. A lot of the basic information required for proper understanding of crop interactions is lacking.

Forage legumes that are suitable for intercropping with cereals need to be identified. The characteristics of such legumes should include:

1. Ability to tolerate shade and still produce high dry-matter and seed yields.
2. Ability to develop canopy rapidly.
3. Annual growth habit, since annuals will fit into the farming systems of SSA better than perennials.
4. Non-climbing habit, as climbing species increase lodging and decrease yield of the cereal. However, climbers with narrow leaves such as vetch may be appropriate.
5. High crude protein content

Dual-purpose legumes, such as cowpeas, groundnuts and lablab which can produce grain and large amounts of fodder could fit into the system.

The contribution of forage legumes to the N economy of soils has received practically no attention. Specific areas that require attention are:

1. Residual effects of intercrops
2. Nodulation and nitrogen fixation
3. Current transfer of N to companion cereals in N-deficient soils
4. Selection or breeding of legumes that have high N content in roots as well as increased root mass. Attempts in this direction have been made by Barnes et al (1984).

There is also a need to determine the optimum planting times and densities as well as the best planting patterns for major cereal-forage legume mixtures. The aim should be to maximise the yields of both intercrops. Fertilization schedules for promising cereal-forage legume combinations need to be determined.

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SOME METHODS FOR IMPROVING FODDER BY INCORPORATING FORAGE LEGUMES IN CEREAL CROPPING SYSTEMS IN THE NIGERIAN SUBHUMID ZONE

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ABSTRACT

The productivity of cattle in the subhumid zone of Nigeria is restricted by the poor feeding quality of the natural vegetation in the dry season. Selective grazing of crop residues provides better quality feed for a short time after crop harvest. Mixed cropping is the standard practice in the Nigerian SHZ and it may therefore be possible to introduce forage legumes into the cropping system to boost the feeding value of crop residues.

Forage legumes can be included in the cropping system by undersowing, inter-row sowing, superimposed cropping or intersod transplanting. Each of these techniques is suited in varying degrees to the different farming and livestock systems. Undersowing and inter-row sowing are likely to be of most interest to mixed farmers, whereas superimposed cropping and intersod transplanting are better suited to agropastoralism and systems in which land is fallowed.

If forage legumes are successfully introduced into the farming systems, they could have a significant impact on cattle production in the subhumid zone.

INTRODUCTION

Crop residues are an important source of feed for livestock in the subhumid zone (SHZ) of Nigeria but their feed quality must be increased if the SHZ is to support a larger cattle population (von Kaufmann, 1979; Powell, 1984; Mohamed-Saleem, 1984; 1985). The SHZ in Nigeria has high rainfall (900-1500 mm) and a long growing season (190-270 days). About 50 to 70% of the area has potential for arable farming (ILCA, 1981). Cultivation is increasing (Bourne and Milligan, 1983), and in an intensively cropped area of the Nigerian SHZ, cattle have been found to spend more than 50% of their grazing time on crop residues early in the dry season. Initially, animals maintain the quality of their diets by selective grazing, but the high-quality portion of crop residues , e.g. immature leaves and grain heads, constitute only about 10% of the total fodder after harvest (Powell, 1984). This is quickly consumed, leaving only very poor-quality fodder during most of the dry season.

Work by ILCA in the SHZ of Nigeria has demonstrated that it is possible to improve the nutritional quality of the diet by including a forage legume in the crop mixture. Techniques for growing forage legumes with grain crops have been developed that require minimal inputs and are compatible with traditional cropping systems, but the identification of appropriate techniques needs careful study of the prevailing farming system.

In West Africa, farmers practise multiple cropping (growing more than one crop on the same piece of land during one calendar year [Beets, 1982]) in order to maximise food security, production per unit land area and labour utilisation. The grain crops grown and husbandry practices are determined not only by the environment but also by socio-economic factors.

There is no record of the inclusion of forage legumes in traditional cropping patterns, and thus their use is novel to farmers in the SHZ. Therefore, forage legumes will have to be gradually introduced into the cropping systems, while preserving most of the traditional husbandry practices. This paper discribes the design and potential application of some techniques to improve fodder in selected cropping patterns in the SHZ.

MAJOR CROPPING PATTERNS IN THE SHZ

The SHZ is considered as a transition zone from tuber and tree crops to cereals and grasses. Some of the main crops grown are listed in Table 1. The cropping pattern in ILCA's case study area in the SHZ is given in Table 2. The choice of crops differs from area to area and between ethnic groups. The main cropping patterns described below for the SHZ cover most of the systems listed by Beets (1982) for tropical countries.

Table 1. Major crops cultivated in the SHZ.

Sorghum (*Sorghum bicolor*)
Maize (*Zea mays*)
Acha (*Digitaria exilis*)
White millet (*Pennisetum typhoides*)
Rice (*Oryza sativa*)
Cocoyam (*Xanthosoma sagitifolium*)
Yam (*Dioscoria* spp.)
Cassava (*Mahihot esculenta*)
Ginger (*Zingiber officinale*)
Lima bean (*Phaseolus lunatus*)
Okra (*Hibiscus esculentus*)
Sweet potato (*Ipomoea batatas*)
Finger millet (Tamba) (*Eleusine coracana*)
Hungry rice (*Digitaria iburea*)
Cowpea (*Vigna unguiculata*)
Pepper (*Capsicum annum*)
Yallo (*Solanum aethiopicum*)
Spinach (*Amaranthus* spp.)
Beneseed (*Sesamum indicum*)
Roselle (*Hibiscus sabdaruiffa*)
Bitterleaf (*Solanum* spp.)
Kenaf (*Hibiscus connabinus*)

Table 2. Cropping patterns in Abet.

Crop enterprise	Mean plot size (ha)	Percentage of total cultivated area
Millet	0.53	40
Sorghum/maize	0.53	15
Sorghum/soya bean	0.30	10
Sorghum	0.34	9
Sorghum/maize/soya bean	0.29	6
Others[1]		20

1. Others: 59 other cropping enterprises involving the above-mentioned and other crops listed in Table 1.

1. **Sole cropping:** A single crop is grown on an area in any given year. Sole cropping is more common among Fulani agropastoralists than amongst cultivators (Powell, 1984).
2. **Mixed cropping with annual crops:** Different cereals such as maize, sorghum and millet are planted at about the same time in regular or irregular patterns (Figures 1 and 2). Vegetables are also included in some crop combinations. Maize is harvested early and the rest are allowed to grow until the end of the season.
3. **Relay cropping with annual crops:** This is the most common system, in which a cereal is planted in rows and another cereal(s) or grain legume(s) is planted later within or between the rows of the first crop (Figure 2). There is always a temporal overlap among different crops.
4. **Sequential cropping:** Around the southern border of the SHZ, farmers plant maize, which is harvested in the milk stage. Grain legumes are then planted on the same land in the same year (Figure 2).

Figure 1. *Diagramatic representation of crop geometry in mixed cropping.*

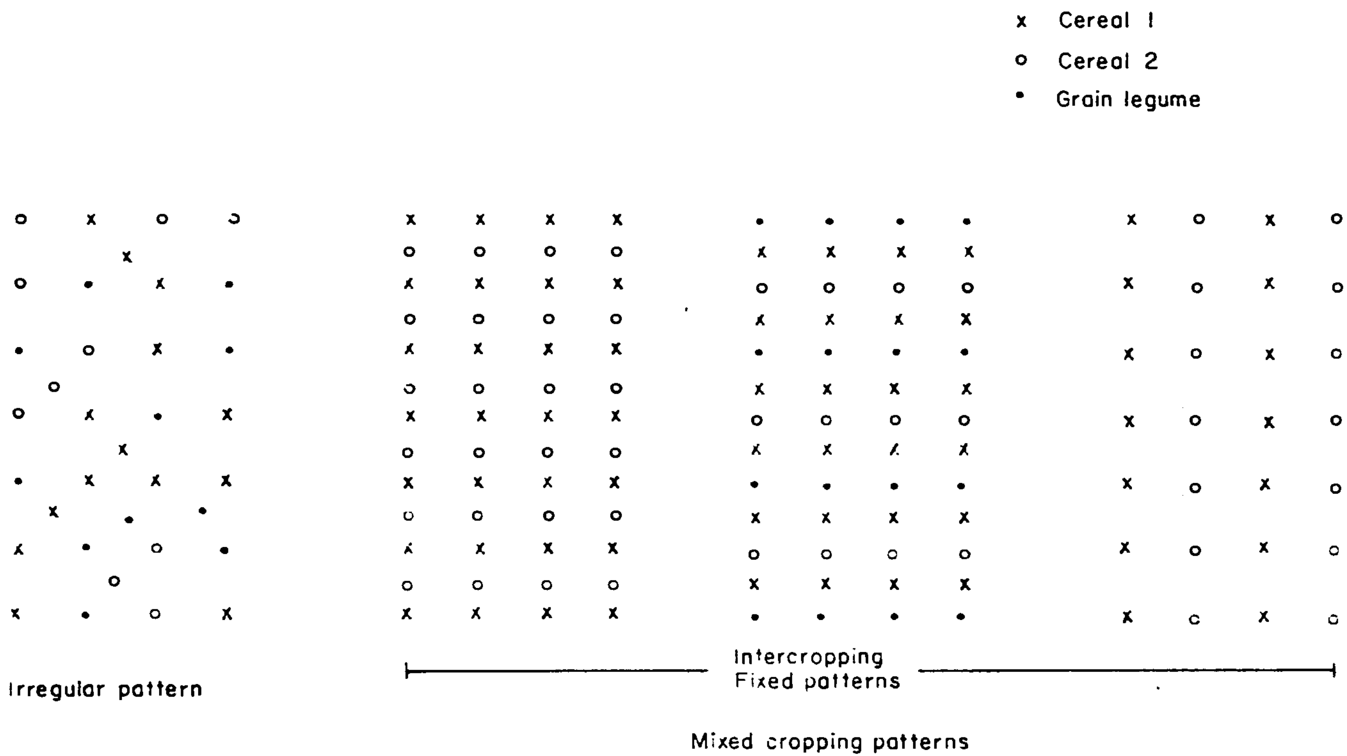
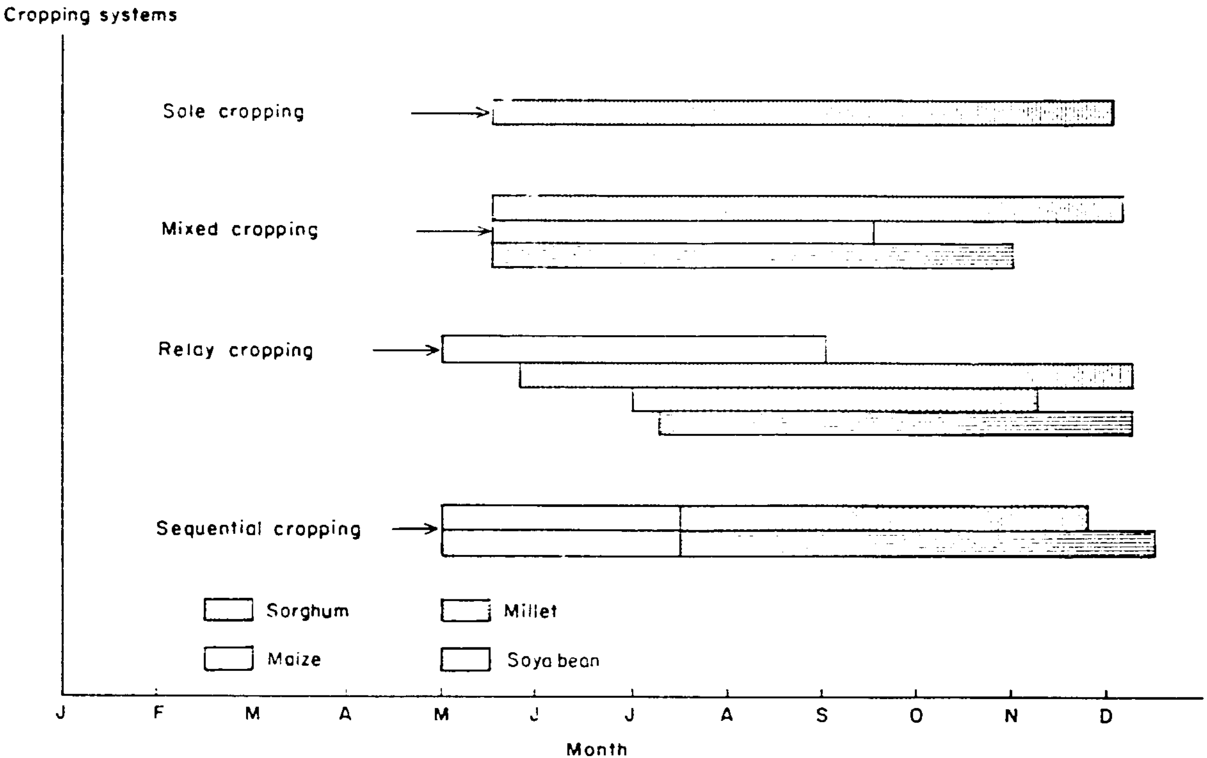


Figure 2. *Generalised cropping systems in the subhumid zone of Nigeria.*



5. **Multi-storey cropping:** Tree crops such as citrus are very common in the southern part of the zone. The trees are widely spaced, and cereals and vegetables are occasionally planted between the rows of trees.

6. **Crop rotations and fallow:** Fallowing is still a common practice for soil regeneration in the SHZ. With the availability of chemical fertilizers, farmers tend to cultivate land near their homestead continuously. If fallowed, the land is recropped after 2 - 5 years, especially in densely populated areas. Rotation of crops is also a common practice. Examples of some cereal crop rotations are illustrated in Figure 3.

METHODS FOR INTRODUCING FORAGE LEGUMES INTO CROPPING SYSTEMS

The different cropping patterns and crop rotations described above offer various options for growing forage legumes in association with food crops. A forage legume may be sown:

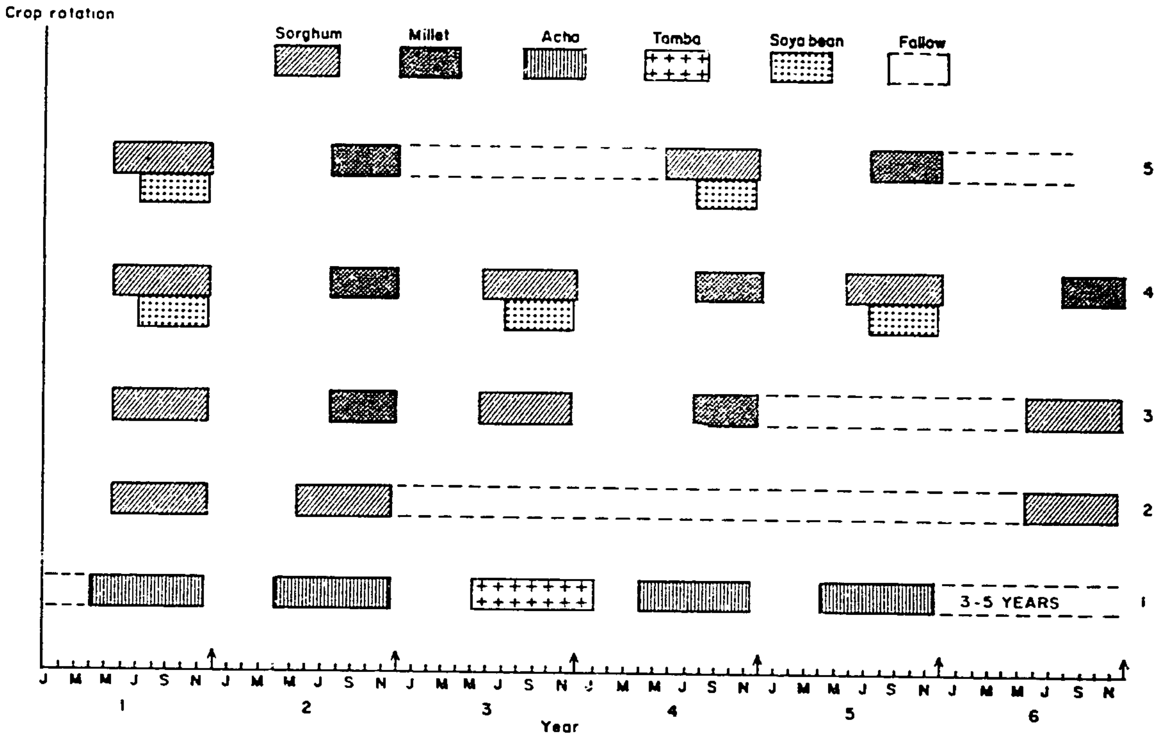
1. After annual crops have established;
2. At the same time as annual crops;
3. To occupy the fallow between two grain crop phases; or
4. Under permanent crops, primarily as a cover crop.

Undersowing annual crops

In the SHZ cereals are usually grown on ridges. Crops such as sorghum, maize and millet are planted either as sole crops at 0.25 to 0.30 m spacing or in mixtures in rows 0.8 to 1.0 m apart.

A cereal may also be grown in a mixture with a legume such as groundnut, soya bean or cowpea. Land preparation has the greatest labour demand among the agricultural operations,

Figure 3. *Some selected crop rotations in the Nigerian Subhumid zone.*



and since this is done for the grain crop, undersowing the crop with a forage legume after the grain crop has established may be the simplest method. Time of undersowing seems to be critical for legumes, as has been found for *Stylosanthes guianensis* cv. Cook and *S. hamata* cv. Verano (Table 3). Planting the stylo 3 to 5 weeks after the sorghum increased the the nutritive value of the fodder without reducing sorghum grain yield, but the delay in undersowing requires additional labour (Mohamed-Saleem, 1985). If the two crops must be planted on the same day, other legumes that are less productive but compete less with the grain crops than stylo may be used (Table 4).

Inter-row sowing

Where a cereal and grain legume are grown in a mixture, the forage legume *S. guianensis* cv. Cook can be planted between the rows. This requires adjustments to the crop geometry. Traditionally, sorghum and soya bean are planted on every ridge (Figure 4b). In this arrangement, single sorghum stands were spaced at 0.25 to 0.30 m in the row and soya bean was planted in between. By planting a pair of sorghum stands at 0.3 m spacings on alternate ridges or rows, a plant population equivalent to traditional populations was achieved. In this arrangement, soya bean was planted in the row between pairs of sorghum stands and stylo was planted on alternate, crop-free ridges to attain a good compromise for grain and fodder production (Figure 4e, Mohamed-Saleem, 1984).

Superimposed cropping

Superimposed cropping is where a cereal is grown concurrently with forage legumes. The cereal is grown during the rainy season, during which the legume, e.g. stylosanthes, is kept under control by weeding or herbicide application until the crop is able to withstand competition. The legume is then allowed to regenerate from seed. This system requires a

Table 3. Effect of undersowing stylo on grain yield of sorghum and total available fodder.

Time of sowing stylo	Grain yield (kg/ha)	Grain yield deviation from C_0	Fodder yield: Crop residue (kg/ha)	Fodder yield: Stylo DM (kg/ha)	Calculated DCP in total fodder (%)	Available crude protein (kg/ha)
- Unimproved sorghum + stylo hamata -						
Sole crop (C_0)	1226		7503 (2.4)		-1.09	180
With crop (C_1)	357	-70	1303 (2.5)	4010 (11.4)	5.02	490
After 3 weeks (C_2)	1224		3719 (2.0)	1729 (12.0)	1.78	281
After 6 weeks (C_3)	1287	+5	4260 (2.2)	702 (12.0)	-0.19	179
After 9 weeks (C_4)	1240	+1	3919 (2.3)	408 (12.8)	-0.28	142
- Improved sorghum + Cook stylo -						
Sole crop (C_0)	2192		8796 (2.9)		-0.64	255
With crop (C_1)	480	-78	2367 (1.4)	4334 (12.9)	4.66	592
After 3 weeks (C_2)	1550	-29	3524 (1.6)	3215 (13.6)	[illegible]34	493
After 6 weeks (C_3)	1918	-13	5385 (1.4)	2464 (13.8)	1.42	415
After 9 weeks (C_4)	1980	-10	7463 (2.9)	456 (14.7)	[illegible].01	283

Values in parenthesis indicate actual percentage of CP in the respective fodder.
DCP (Digestible Crude Protein) = 0.899 CP - 3.25

Table 4. Grain and fodder yields of sorghum when planted together with forage legumes.

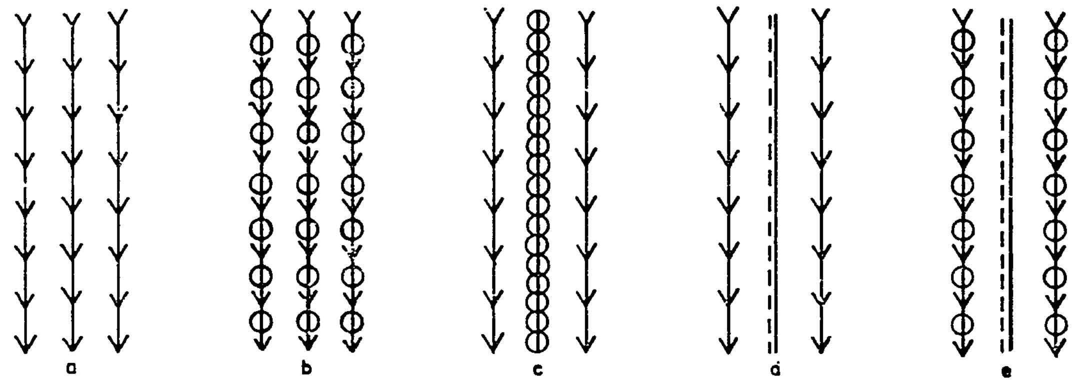
Crop mixture	Grain yield	Crop residue	Legume DM	Total fodder
	--------------kg/ha	--------------		
Sole sorghum	1296	4667		
Sorghum + *S. hamata*	313	1685	2778	4463
Sorghum + Cook stylo	388	1555	2063	3618
Sorghum + *M. atropurpureum*	356	2111	1296	3407
Sorghum + *C. pascuorum*	1019	2981	1204	4185
Sorghum + *A. vaginalis*	1092	2519	926	3445
Sorghum + *M. lathyroides*	1297	2741	1481	4222

large reserve of legume seed in the soil and is dependent on the return of a large amount of seed to the soil after each growing season. Presence of seeds with different degrees of dormancy will ensure regeneration of the legume after land preparation and weeding, which eliminate seedlings from seeds that germinate early in the season.

Intersod transplanting

Transplanting millet is a standard practice in the SHZ. Occasionally, when rains are late or establishment is poor after early planting, sorghum is also transplanted. In an experiment, sorghum and millet transplanted into 30-cm-wide flat strips cut through an established *S. hamata* cv. Verano pasture at 1-m intervals decreased grain yields by 20-22% as compared with traditional practice of planting on ridges (Mohamed-Saleem, 1984). But the labour required for cutting the strips with a hoe was only one-third of that required for ridging. However, sorghum transplanted on ridges within established stylo pasture gave much higher grain and fodder yields than sorghum planted in areas without stylo (Table 5).

Figure 4. *Effect of crop geometry on grain and fodder yields of sorghum – soya bean – stylo mixture.*



Yields

		a	b	c	d	e
Grain kg/ha	sorghum	1491	1201	1558	1390	1331
	soya	-	91	112	-	68
Fodder kg/ha	sorghum	6159	5170	5549	5262	4813
	stylo	-	-	-	1803	1360

Table 5. Effect of land preparation and method of crop establishment within stylo on grain and fodder yields of sorghum, Kurmin Biri, 1983.

		Yield (kg/ha)		
Land preparation	Planting method	Grain	Crop residue	Stylo DM
Sorghum without stylo				
Ridge	Seed	292	2750	
	Transplant	795	4833	
Strip hoe	Seed	84	1646	
	Transplant	583	3667	
Sorghum with *S. guianensis* cv. Cook				
Ridge and no weedicide	Seed	342	2617	1440
	Transplant	1093	4315	1512
Strip hoe and no weedicide	Seed	94	1313	2205
	Transplant	240	2050	2058
Ridge and weedicide	Seed	531	3375	748
	Transplant	1563	5716	760
Strip hoe and weedicide	Seed	250	2207	1080
	Transplant	563	3750	942

CROP-LIVESTOCK PRODUCTION SYSTEMS AND SELECTION OF TECHNIQUE FOR FODDER IMPROVEMENT

There are four main crop-livestock production systems in the SHZ:

1. Cropping, with residue grazed by pastoralists' cattle.
2. Main emphasis on cropping but with some livestock.
3. Settled agropastoralism: main emphasis on livestock, with subsistence cropping.
4. Settled pastoralism with little or no cropping.

The first is predominant in the Nigerian SHZ, and thus there may not be motivation to improve fodder since the livestock do not belong to the farmers. At present there is no cash return from crop residues in the SHZ, in contrast to the more arid north of the country, where crop residues are sold. Undersowing and inter-row sowing have been found to be more readily taken up by farmers who also have cattle.

Pastoralists crop not more than 1 ha of land because of problems with acquiring land and shortages of labour, which is needed for land preparation. Thus, relay cropping of cereals and forage legumes to provide better-quality forage will have little effect because of the small area cropped. Increasing the feeding value of crop residues by undersowing/ inter-row sowing with legumes may be practicable for farmers who own some animals for milking or traction.

Undersowing and inter-row sowing with a forage legume in the last year of the cropping cycle may be useful as means of establishing a legume pasture. Growing *Stylosanthes* spp. for 1 to 3 years has been found to improve the physical conditions and N status of soil (Mohamed-Saleem, 1984), and growing a legume pasture may be more beneficial than a natural fallow, especially where the fallow period is short due to higher pressure on land (e.g. Figure 3, patterns 2, 3 and 5).

Superimposed cropping and intersod transplanting are suitable for growing cereals within established legume pastures, e.g. fodder banks, or where wet-season grazing is in short supply. Where shortage of land is a constraint for agropastoralists, superimposed cropping offers the possibility of intensive use of land for both grain and fodder production. In areas of low cropping index, an individual farmer often owns more land than he cultivates. Settled pastoralists are able to secure uncropped lands for establishment of fodder banks. Superimposed cropping and intersod transplanting allow areas that are under improved pasture to be cropped without having to resow the pasture annually.

Since transplanting of crops can be delayed until the middle of the growing season, the legume pastures could also offer valuable grazing early in the growing season. By using short-duration, high-yielding varieties and hybrids of maize and sorghum, planting can be delayed, whereby a given piece of land could provide improved grazing early in the growing season and later be planted with a grain crop. This would be useful in areas where the extent of cultivation restricts the area available for wet-season grazing.

CONCLUSIONS

When crops are grown in mixtures, the yield of each crop is usually less than when the crop is grown in pure stand, but the farmer is interested in the combined yield of the mixture. However, forage crops do not contribute directly to human food and have no monetary value in most of the SHZ, and thus reduction of the grain yield of the companion crop is not acceptable to the farmer. Therefore, if farmers in the SHZ are to adopt the practice of growing forage legumes in combination with grain crops, reductions in grain yield must be avoided.

The competition between forage legumes and grain crops can be minimised by changes in planting geometry and times of planting of crops. If these practices are incorporated into the farming systems in the SHZ of Nigeria they will help to increase both the quantity and the quality of livestock feed available.

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EFFECT OF INTERCROPPING COWPEA ON DRY-MATTER AND GRAIN YIELD OF MILLET IN THE SEMI-ARID ZONE OF MALI

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ABSTRACT

Intercropping cowpea and millet for one year can increase the grain yield of a following millet crop by 15 to 103%. A pure crop of cowpea was also shown to increase the yield of a following millet crop by 16 to 64%. The optimum ratio of cowpea to millet varied, depending on whether fertilizer was applied. When 33 kg P/ha was applied, a mixture containing 45% cowpea gave satisfactory yields of both crops, but without P application including more than 15% cowpea in the mixture reduced millet yields. A single application of 33 kg P/ha increased millet yield by a total of 19.4 kg of grain/kg P over the following 3 years.

Other experiments carried out under two rainfall regimes showed that cowpea yields suffered less than millet yields from the association of the two crops. The 50:50 millet:cowpea ratio provided higher yields than sole cropping under severe drought conditions. Soil moisture retention appeared to be greater under a millet crop than under cowpea.

INTRODUCTION

The agropastoral system in the area studied is changing. Agriculture is penetrating more and more into the north of the area, while livestock production is moving increasingly to the south. The pastoralists are becoming increasingly sedentarised and the population is increasing by 2.5% per annum. As a result the cultivated area in Mali is increasing by 2.6% per annum. The livestock population is increasing by 2 to 4% per annum and the total population (camel, bovine, caprine and ovine) has reached 5.8 million TLU (Tropical Livestock Units) (FAO, 1984). The number of livestock per pastoralist and per farmer is increasing.

As a result of the last two changes, there is a shortage of forage, which is aggravated by increased competition between animal and crop production. This competition is both qualitative (N and energy) and quantitative. The greatest feed shortages are experienced towards the end of the dry season, in April, May and June.

Millet yields in Mali average only about 500 kg of grain per hectare. The low yield is partly the result of the reduction of fallowing, resulting in reduced soil fertility. The soil of the area is poor and the quantity and distribution of rainfall uncertain, making farming risky.

Millet, which is the only cereal that can survive under these conditions, provides between 70 and 95% of human food energy, and is grown as a monocrop on 60% of the cropped land. Cowpea is grown on about 7% of the land, and the grain is used for human consumption, while the stems and leaves are used for animal feed.

ILCA's interest in cowpea stems from the desire to increase forage availability while maintaining or increasing food production, which is the farmers' priority. We would also like to see forage used mainly for feeding oxen, which provide draught power on the farms. Oxen are often in a poor state of nutrition at the start of the ploughing season, since most of the heavy work takes place at the beginning of the rainy season (June-July), when feed from pastures is in short supply. If these animals are supplemented with 2 to 3 kg of dry matter per day, they will be able to provide more work, thereby increasing the amount of land that can be cultivated.

MATERIALS AND METHODS

The study area lies between the long-term average rainfall isohyets of 300 and 600 mm of annual rainfall. The rainy season spans three to four months, from June-July to September-October. Table 1 gives rainfall data for the 4 years of the trials and for the two sites. The rainfall totals in the first 2 years of trials at Niono were above average at more than 400 mm, but the following 2 years were well below average with only about 200 mm of rainfall. The Banamba site was wetter than the Niono site, but received less rainfall than expected.

Table 1. Useful rainfall at Niono (1981-1984) and Banamba (1984)

	Rainfall (mm)	
Year	Niono	Banamba
1981	411	-
1982	478	-
1983	196	-
	(250)	-
	220	406
1984	(335)	(445)

Note: Figures in brackets give the total annual rainfall.

Niono is located at 14° 15' N and 5° 59' W, at 227 metres a.s.l. The ranch on which the trials were done is in the fossil delta of the Niger, west of the central delta, and consists of aeolian dunes. The soils range from loamy sands to sandy loams, and are classified as ferisallitic (French system), eutric nitosol (FAO-UNESCO), or ultic haplustalf (Soil taxomony USA) (see Penning de Vries and Djiteye, 1982). Some physical and chemical characteristcs of a soil representative of that at the test site are given in Table 2.

Table 2. Physical and chemical characteristics at various depths of loamy sand soil from Niono, 1983.

Depth (cm)	C (%)	N (%)	Total P (ppm)	Sand Coarse	Sand Fine	Loam (%) Coarse	Loam (%) Fine	Clay (%)
0 - 10	0.3	0.01	55.2	16	69	7	3	5
10 - 20	0.3	0.01	55.2	15	70	6	2	7
20 - 30	0.1	0.02	55.2	14	69	6	4	7
30 - 40	0.1	0.02	55.2	14	68	6	2	10
40 - 60	0.1	0.01	55.2	14	69	3	3	11
60 - 80	0.1	0.01	64.8	13	69	6	2	10
90 - 100	0.1	0.01	55.2	12	71	4	3	10

The data show that N, C and total P levels are very low. The soil is a loamy sand, with almost 70% fine sand in each soil layer; the percentage of coarse sand decreases with depth. The proportion of loam is always less than 10%, while the proportion of clay increases with depth to a maximum of 10% in the deepest horizons.

Banamba, a new site chosen in 1984, is located at 13° 33' N, 7° 25' W, in an area that receives more rainfall than Niono. The soils were not analysed, but are of a sandy type in the leached ferruginous soils or aridic haplustalfs category.

Two trials were conducted over 3 consecutive years (1981-83). The first examined the residual effects of a cowpea variety grown in association with millet. The second was aimed at determining the optimum ratio of cowpea to millet to maximise the yields of both crops.

In 1984, a more basic trial was conducted at two sites to gather more infromation on mixed cropping of these two species.

Experiment 1 (1981-83)

The soils on which the trials were planted had been under millet monocrops in the previous year. The two crops were planted in different association patterns and in different cropping sequences. The close association of the two species on the same ridge was designated by MC, followed by the index 1 or 2 to indicate whether this cropping pattern was applied for 1 or 2 years. Millet and cowpea planted on alternate hills within the same ridge was designated M/C. The prefix 2 or 3 indicates the year in which this treatment was applied. Pure stands of millet were planted for 3 consecutive years, for 2 consecutive years or in only the last year of the trial. A pure stand of cowpea followed by a pure stand of millet was also grown.

Early-maturing (90 days or less) local varieties of millet (*Pennisetum americanum* (L) Leeke) were used. Three varieties of cowpea (*Vigna unguiculata* (L) Walp) were used: Voutolomavo, from Mali, in 1981; TVx,33-1J, from IITA in Nigeria, in 1982, and TN 38-63, from Niger, in 1983.

The trial was laid out in randomised blocks with four replicates. Plot size was 10 m x 10 m, with a useful subplot size of 6 mx 6 m. Inter-ridge spacing was 90 cm in all treatments. In pure stands of each crop and in treatments in which millet and cowpea were grown in the same hill within the ridge, spacing between hills was also 90 cm. In treatments in which the two crops were planted in separate hills, the spacing between hills was 45 cm. Thus, spacing between two hills of the same crop was 90 cm in all treatments. In each treatment there were 12 345 hills per hectare, each containing two millet plants, plus two cowpea plants where appropriate.

The plots were cultivated with an ox-drawn plough after the beginning of the regular rains. Seeds were hand sown on the ridges. In 1981 and 1982, sowing took place in mid-July, while in 1983 sowing took place at the beginning of August because of the late start of the rains. The crops were thinned 15 days after emergence to 2 plants/hill. Weeds were controlled with two or three hoeings using a *daba* (a hoe with a short handle). Cowpea harvest started in mid-September, while millet harvest continued through the third week of October.

Experiment 2 (1981-83)

This trial investigated the traditional practice of mixing the two species in the same hill. Plots were planted with various proportions of legume in the stand (0, 15, 30 and 45%), with (P+ = 33 kg P/ha) or without (P-) application of single superphosphate. The fertilizer was applied only in the first year in order to study the residual effects of the phosphate. Planting densities and plant populations are shown in Table 3. Experimental design and cultural practices were the same as in Experiment 1.

Table 3. Planting density and plant population of treatments, Experiment 2, Niono, 1981-83.

Cowpea		Millet	
(%)	Plants/ha	(%)	Plants/ha
0	0	100	24 690
15	3 700	85	24 690
30	7 400	70	24 690
45	11 111	55	24 690

Experiment 3 (1984)

The third trial investigated the effects of varying proportions of the two crops grown in association, using a replacement-series model. Treatment 1 (T_1) was a pure stand of millet; T_2 was 75% millet and 25% cowpea; T_3 was 50%

millet, 50% cowpea; T_4 was 25% millet, 75% cowpea; and T_5 was a pure stand of cowpea. The number of hills of each crop in each treatment is shown in Table 4.

Table 4. Number of millet and cowpea hills per hectare in each treatment, Experiment 3, Niono and Banamba, 1984.

Treatment	Millet	Cowpea
T1 (100% M)	12345	-
T2 (75% M-25% C)	9259	6173
T3 (50% M-50% C)	6173	12345
T4 (25% M-75% C)	3086	18518
T5 (100% C)	-	24690

The trial was laid out in randomised blocks with three replicates. Plot size was 7.2 m x 7.2 m, and yield estimates were made from a subplot of 3.6 m x 3.6 m. The local millet varieties were again used, but the cowpea variety was 59-25, from Colombia.

The water content of the soil under the different cropping patterns was investigated using a gravimetric method at the Niono site.

RESULTS

The association between millet and cowpea had no marked phenological effects on either species, except for a slight delay in the flowering of millet in the MC treatment (Trial 1). The application of fertilizer in the first year of Trial 2 increased early vegetative growth of millet during all 3 years of the trial, but had little effect on cowpea.

Yields were very low in the third and fourth years (1983 and 1984), due to poor rainfall. This makes interpretation of the results difficult. However, the following observations can be made from the results.

Growing millet and cowpea in mixtures decreased the yield of each crop compared with yields of each in pure stand. Intercropping millet and cowpea for one year reduced the grain yield of millet by 23% (M/C, treatments e and j vs treatment a, Experiment 1, Table 5), while growing the crops in the same hill (MC) reduced the grain yield of millet by 31% (treatments c and i vs treatment a, Experiment 1, Table 5). When these associations were practised over 2 consecutive years the yield reduction was larger at 39% (Treatments d and f vs treatment a, Experiment 1, Table 5). Thus it is better to grow the crops in these associations for only one year, followed by a pure stand of millet.

Given this observation, the best, or least disadvantageous, association seems to be alternate cropping (M/C), since this gave the largest increase in yield of a subsequent millet crop (Figure 1, M/C_1 followed by M). This type of intercropping of millet with cowpea was observed to increase the yield of the subsequent millet crop by 103% (2M/C, treatment j vs a, Experiment 1, Table 5). However, this yield increase is based on the low yields in 1983, due to the exceptionally low rainfall in that year, and similar yield increases should not be expected in more normal years.

Cowpea grown in pure stand for one year increased the grain yield of a subsequent crop of millet by 16% (Treatment b vs treatment a, Experiment 1, Table 5), while growing cowpea in pure stand in the second year increased the yield of the subsequent millet crop by 64% (Treatment h vs treatment a, Experiment 1, Table 5). The dry-matter yield of the cowpea crop was larger in the second year, but this finding should be treated with caution as the cowpea varieties used and rainfall differed between years. The yields of cowpea in intercropped treatments were very much lower than those of cowpea grown in pure stand.

The effect of the different cowpea:millet ratios (Experiment 2) was affected by P application. Application of P in the first year increased the grain yield of millet by 7.7, 9.7 and 2 kg/kg of P in the first, second and third year, respectively. The response of millet to P was much

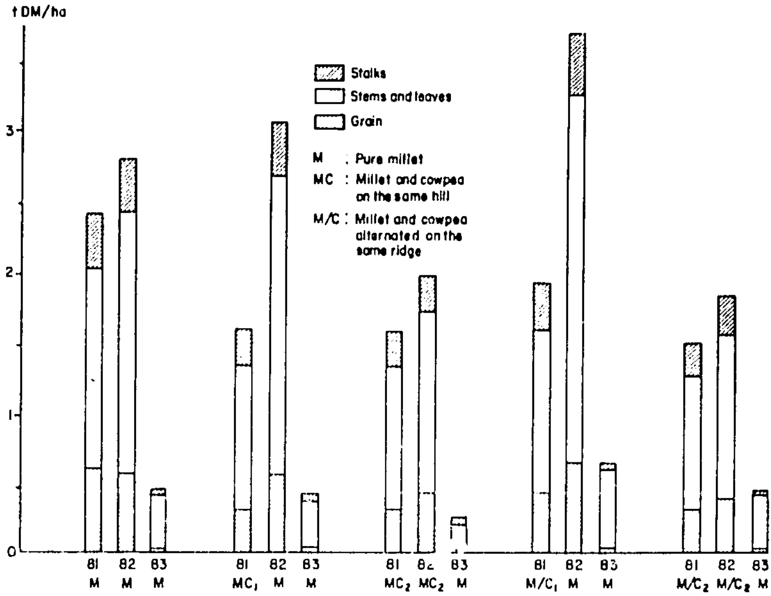
Table 5. Millet yield (grain) and cowpea yield (stems and leaves) over 3 consecutive years of trials with different association patterns (M,C,MC on M/C and with various legume densities and with and without P (33 kg P/ha).

Exp. 1 Index	Treatment 1981	Treatment 1982	Treatment 1983	Millet yield (kg/ha) 1981	Millet yield (kg/ha) 1982	Millet yield (kg/ha) 1983	Cowpea yield (kg DM/ha) 1981	Cowpea yield (kg DM/ha) 1982
a	M	M	M	628	589	36	-	-
b	C	M	M	-	686	31	968	-
c	MC_1	M	M	327	604	44	500	-
d	MC_2	MC_2	M	327	460	23	562	1268
e	MC_2	MC_2	M	467	679	54	671	-
f	M/C_1	M/C_2	M	341	418	28	542	956
g	M/C_2	M/C_2	M	-	620	36	-	-
h	-	2M	M	-	-	59	-	2869
i	-	2C	M	-	505	47	-	942
j	-	2MC	M	-	479	78	-	851
k	-	2M/C	3M	-	-	36	-	-
F Test				NS	NS	NS	*	**
lsd				/	/	/	295	825

Exp. 2 Application	Density (%)	Millet yield (kg/ha) 1981	Millet yield (kg/ha) 1982	Millet yield (kg/ha) 1983	Cowpea yield (kg DM/ha) 1981	Cowpea yield (kg DM/ha) 1982	Cowpea yield (kg DM/ha) 1983
	0	1004	768	95	-	-	-
P+	15	859	844	154	58	68	90
	30	1030	913	76	116	114	100
	45	811	1096	108	234	243	163
	0	854	547	63	-	-	-
P-	15	676	647	52	69	88	63
	30	776	647	52	167	183	124
	45	382	451	10	217	190	95
F test application		*	*	*	NS	NS	NS
LSD		167	218	63	/	/	/
density		*	NS	NS	**	NS	*
LSD		287	/	/	62	/	32
application + density		NS	NS	NS	NS	NS	NS

NS = not significant
* = significant at p = 0.05
** = significant at p = 0.01
LSD: least significant difference for the same level of significance as the F-test.
M = millet in sole cropping and C = Cowpea in sole cropping
MC = millet and cowpea in the same hill
M/C = millet and cowpea alternated.

Figure 1. *Millet yield components for the five systems of rotation over the 3 years of Experiment I, Niono (1981, 1982 and 1983).*



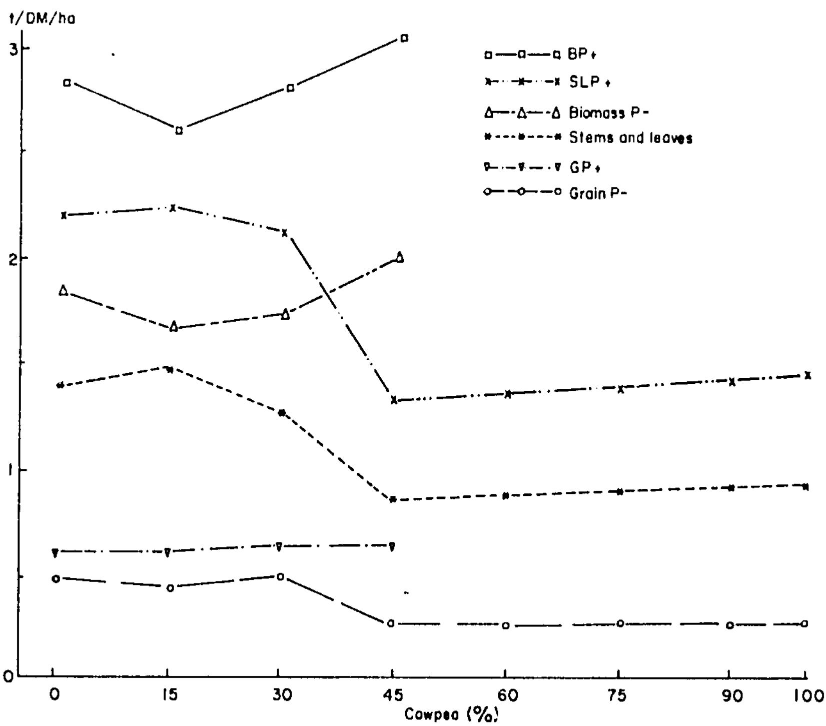
larger when grown in a mixture containing 45% cowpea (Table 6). This mixture gave good yields of both components of the mixture. However, it seems that a mixture containing 30% cowpea gives the best millet yields. When P was applied, increasing the proportion of cowpea in the mixture increased the dry-matter (stem and leaf) yield of millet (Figure 2). Yields of cowpea were very low, especially with regard to grain production, but increased with the proportion of cowpea in the mixture. Applying P reduced the DM yield of cowpea by 30% when cowpea comprised 30% of the mixture, but increased cowpea DM yield by 27% in the mixture containing 45% cowpea (Table 5).

In the dry year of 1984, cowpea yields were reduced less than those of millet. Under the better conditions in Banamba, cowpea seemed to be insensitive to the presence of millet when grown in association, while the millet seemed to

Table 6. Response of millet grain yield to P application in relation to the proportion of cowpea in the mixture, Experiment 2, Niono, 1984-1983.

Legume (%)	kg Grain/kg P
0	12.2
15	14.5
30	15.4
45	35.4

Figure 2. *Effect of cowpea (% in association) and P (33 kg/ha: P+) on yield components of millet (average for 1981–83), Niono.*



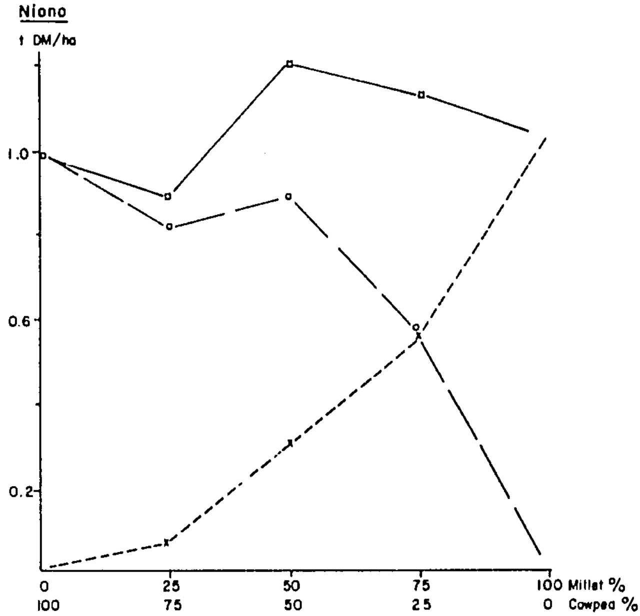
benefit from the association. This can be seen from Figure 3: a straight line indicates that there is no influence on the species, while a curve indicates an effect of the association.

From Table 7 it is clear that increasing the ratio of one species in the mixture leads to higher yields, at least at the wetter site of Banamba. However, at Niono the pattern is less clear, particularly with regard to millet grain yields (see Table 7, T_1 vs T_2).

Figure 4 indicates the importance of the millet root system in retaining soil moisture. The soil profile tended to dry out more rapidly under mixtures containing a small proportion of millet than under those with a large proportion of millet in the mixture, particularly in August and September. However, in terms of production, the results differed between the sites. At Niono (220 mm annual rainfall) the best association consisted of 50% of each species, which gave an increase of 24% in total biomass yield. At Banamba the best association was 75% millet and 25% cowpea, which yielded a total of 5 t DM/ha (Figure 3).

Experiments carried out by ICRISAT in Mali between 1979 and 1983 in the 500 to 1000 mm rainfall zone showed that timing of intercropping operations is important. Early sowing of millet and/or cowpea in alternate rows increased yields, particularly of cowpea, as did increasing the proportion of cowpea in the mixture. Including cowpea in the mixture did not decrease the yields of the cereal except under conditions of poor rainfall or low N. It is possible to sow the two crops at different times, sowing the millet first and then the cowpea, but sowing of the cowpea should not be delayed too long, or yield may be reduced. Moreover, if the cowpea is harvested early some N might become available to the millet crop from the decomposition of the N-rich nodules of the cowpea. Recent experiments by the Projet Sectoriel de l'Elevage, demonstrated that intercropping cowpea and millet within the row gave higher millet grain and straw yields than planting in alternate lines or in alternate double lines (Bartholomew, 1985).

Figure 3. *Millet and cowpea biomass and cumulative biomass for mixtures of various proportions at Niono (200 mm rainfall) and Banamba (400 mm), Experiment 3, 1984.*



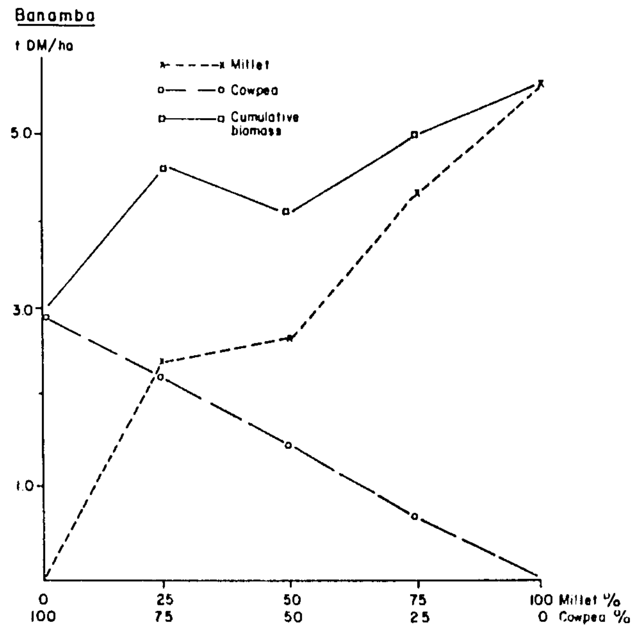


Table 7. Millet yield (grain and stems + leaves) and cowpea yield (grain and stems + leaves) in Experiment 3, Niono and Banamba, 1984.

		Millet yield (kg/ha)		Cowpea yield (kg/ha)	
Site	Treatment	Grain	Stems + leaves	Grain	Stems + leaves
Niono	T_1	6	815	-	-
(220 mm)	T_2	52	445	7	568
	T_3	2	293	45	902
	T_4	1	58	34	821
	T_5	-	-	38	994
F test		2.6NS	9.2**	1.5NS	7.7**
LSD		-	404	-	260
Banamba					
(400 mm)	T_1	1525	3511	-	-
	T_2	1049	2869	143	671
	T_3	741	1601	318	1479
	T_4	539	1621	403	2222
	T_5	-	-	449	2902
F test		11.7**	6.7**	7.0**	16.9**
LSD		592	1713	312	1971

T_1 = 100% millet; T_2 = 75% millet, 25% cowpea; T_3 = 50% millet, 50% cowpea; T_4 = 25% millet, 75% cowpea; T_5 = 100% cowpea.

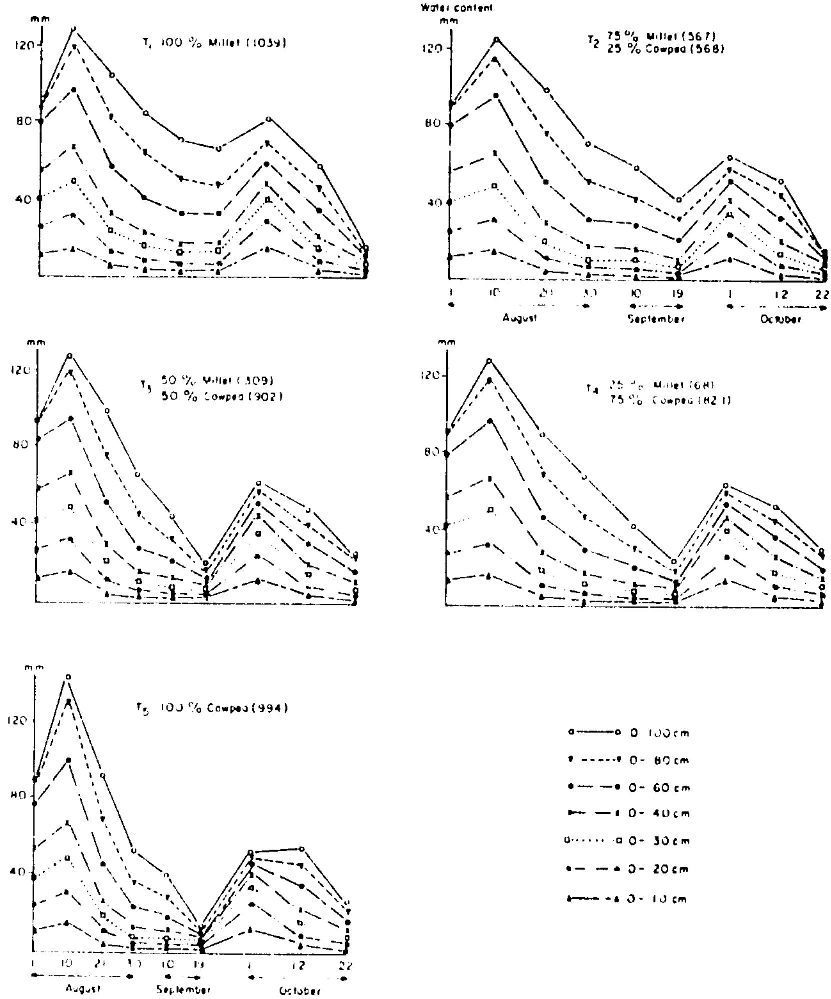
NS = not significant.

* = significant at $P<0.05$.

** = significant at $P<0.01$.

LSD = least significant difference at the same level of significance as the F test.

Figure 4. *Changes in soil water content (mm) with time under three millet/cowpea mixtures and millet and cowpea monocrops. Experiment 3, Niono, 1984. (Figures in parentheses are total biomass yields [kg DM/ha] for each crop)*



CONCLUSIONS

It appears that the benefit of growing millet and cowpea in association depends upon the growing conditions. In semi-arid zones, farmers will only grow mixtures of millet and cowpea if the yield of the cereal is not reduced, since production of the cereal is their priority. Under these conditions the farmer will not plant more than 6000 cowpea plants per hectare, since higher populations of cowpea reduce millet yield. Our experiments showed that if P fertilizer is available, the farmer can increase the proportion of the legume in the mixture to 50% without decreasing millet yields.

The farmers' current practice is to sow millet and cowpea in the same hill. The alternative practice of having alternate hills of millet and cowpea gives higher yields but makes sowing and harvesting more complicated. Sowing millet and cowpea in alternate lines appears to be the most satisfactory form of intercropping in terms of production, but is perhaps more susceptible to the potentially serious problem of damage by livestock.

However, while growing a pure stand of cowpea seems to benefit the subsequent cereal crop, this cropping system might favour the development of insect pests to which cowpea is susceptible. Without insect control, yields of the cowpea will suffer. Growing the legume in association with the cereal overcomes this problem, and reduces greatly the incidence of insect pests in the legume.

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A PRELIMINARY EVALUATION OF LEGUME LEY FARMING IN THE AUSTRALIAN SEMI-ARID TROPICS

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ABSTRACT

The notion of using sown pasture leys in rotation with annual crops to maintain soil fertility, reduce erosion and improve animal production has a long history in agricultural research in the savanna zone of Africa. However, research has shown little advantage of sown grass leys over vegetated fallow. The question of whether a legume ley would better provide the desired benefits has remained largely unanswered because, until recently, no tropical legumes that were sufficiently productive in the semi-arid tropics were available. This paper reports the findings from 4 years of a pilot study at Katherine, N.T., of a system in which cattle graze natural pastures in the wet season and croplands in the dry season. Croplands consist of one-third maize or sorghum and two-thirds pasture legume (2:1 rotation). The main objectives were to quantify (1) the contribution of grazed legume leys to the soil N supply of a succeeding cereal crop, (2) the benefits of legume leys to cattle growth and (3) the ability of legume pastures to withstand invasion of nitrophilous weeds. Three legumes, *Stylosanthes hamata* cv. Verano, *Alysicarpus vaginalis*, and *Centrosema pascuorum*, were compared.

In the one year that facilitated a field bioassay of N contribution, it is estimated the legume ley provided the equivalent of about 40 kg of fertilizer N/ha.

Steers on croplands in the dry season gained an average of 0.63 kg/day. Annual gains over 3 years averaged 123 kg, 30 kg more than cattle on natural pastures continuously.

Even within 2 years, it is clear that invasion of annual grass can be a problem, particularly in leys of *A. vaginalis*. In the longer term, the general encroachment of an aggressive perennial grass is judged to be an even greater threat.

Priority areas for further research in evaluating the potential of this farming strategy are identified.

INTRODUCTION

The early impetus for research on ley farming in the savanna zone of Africa came with appreciation of the especially rapid decline of soil productivity when crop production was intensified. Colonial British agriculturalists, in particular, saw 'alternate husbandry', which had served agriculture in Britain so well, as an obvious solution where grazing animals were already important and the economic prospects for chemical fertilizers very limited. Their research aim was to provide 'the basis for a new and constructive system of pastoral agriculture' (Ross and Bumpus, 1944, quoted by Whyte, 1944, p. 34).

In the absence of a well adapted legume species, their attention focused on the benefits of sown grasses, but after five decades of research in East, West and southern Africa it can be safely concluded that grass leys have shown no advantage to crop yields over natural vegetated fallows (Webster and Wilson, 1980, p. 373). Contributions to nutrient supply to the crop phase are, at best, modest and short-lived (Barnes 1981; Stobbs 1969), and soil structure is improved for only one season on light textured soils (Wilkinson, 1975) and for little more than 2 years on heavy soils (Stephans, 1967). The persistent pursuit of a grass ley system for the tropics is understandable since it was not until the 1960s, 30 years after the start of the grass ley work in Africa, that British workers concluded that the main benefit of a temperate pasture ley to the succeeding crop is the nitrogen supplied (Cook 1967, p. 413), and that the legume component of the ley is crucial.

During the 1970s, well adapted pasture legumes for the savanna zone became available, and interest in tropical legume leys was renewed (Jones and Wild, 1975, p. 217; McCown et al. 1979; Webster and Wilson, 1980, p. 374). In 1978, research commenced at Katherine, Australia, to test the feasibility of a no-till, legume-ley system for the semi-arid tropics. The rationale, research strategy and preliminary results of the study of a number of components are reported by McCown et al (1985). This paper reports findings from the only experiment that was of sufficiently large scale to allow realistic grazing management. Thus it provides the only animal production information available from our work to date, as well as the only opportunity to observe the system working as a whole.

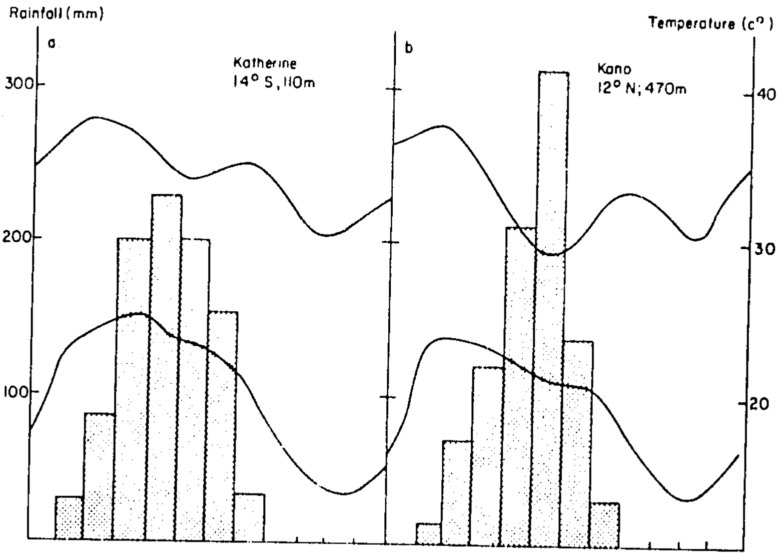
The objectives of the experiment were to measure (1) the contribution of grazed legume leys to the N supply for a cereal crop in rotation; (2) the benefits of legume leys to cattle growth, and (3) the ability of legume pastures to withstand invasion of nitrophilous weeds, particulary grasses, and to regenerate.

ENVIRONMENT AND METHODS

The physical environment for agriculture

The climate and soils of the region around Katherine, N.T., Australia, have been described by Williams et al (1985). Katherine lies at 14^{o} S at an elevation of 108 m. It has a mean annual rainfall of 930 mm, almost all of which falls during a hot summer (Figure 1a). Comparison with Figure 1b shows the close similarity of rainfall and temperature regimes to those of Kano, Nigeria. Experiments have shown that the climate is suitable for growing crops, including grain sorghum, maize, bulrush millet, cowpeas, soyabean, mung beans and peanuts, the main constraint being a risk of water deficits either early or late in the season. Rainfall erosivity is high and soil erosion is a major threat to agricultural productivity.

Figure 1. *Mean monthly rainfall (histogram), and maximum and minimum daily temperatures at (a) Katherine, Australia, and (b) Kano, Nigeria.*



Beef cattle production on natural pastures is seriously constrained by the long dry season and low soil fertility. Winter rainfall events sufficient to benefit cattle nutrition by new grass production occur in many fewer years than in other areas of the Australian semi-arid tropics (McCown, 1982). However, this reliable dryness of the dry season is an important asset with sown legume pastures. In only one year in nine is there sufficient rain to cause spoilage of legume 'standing hay' much before opening rains of the new growing season (McCown, unpublished).

The soils of agricultural importance are Oxic Paleustalfs (Rhodic luvisols) ranging from clay loams to sands. The available water range is low (7-10%) even when clay content is high (Williams et al, 1985). Invariably the soils are deficient in N and P and occasionally in S or Zn. They are apedal and prone to slake when wet and to crust when dry.

Treatments

The experimental area consisted of 180 ha of natural grass/Eucalyptus open woodland and 3.6 ha of cropland. Within the cropland, one year of cereal crop was rotated with 2 years of legume pasture. The crop sequences for a 4-year period are shown in Table 1. Each sequence was followed in three blocks, each of which was sown to one of three legume species; *Stylosanthes hamata* cv. Verano, *Alysicarpus vaginalis* (Martin and Torssell 1974), and *Centrosema pascuorum* CPI 55697 (Clements et al, 1983). Neither the legume treatments nor the natural pastures were replicated. In the dry season, 12 steers were transferred from the natural pasture block to croplands where they had access to two-thirds of the area as dry legume and one-third as cereal residue. Six steers remained on natural pasture. Cattle in the croplands rejoined those on natural pastures following rainfall sufficient to initiate new growth on the natural pastures.

Table 1. Identification of crop sequences and the schedule of component crops and leys.

Crop sequence code	1981/82	1982/83	1983/84	1984/85
A	Maize	Ley 1	Ley 2	Maize
B	Ley 1	Sorghum	Ley 1	Maize
C	Ley 1	Ley 2	Maize	Maize

A further treatment split was that of the grain crop areas into two: in one half all weeds (including legumes) were controlled (IC_o) and in the other grass weeds were controlled but pasture legumes allowed to form an understory or intercrop (IC_+).

In summary, the croplands area was divided as follows:

Three legume species (grazed separately)	3.6/3 = 1.2 ha
Three rotation phases (Ley 1, Ley 2, Crop)	1.2/3 = 0.4 ha
Two crop mixtures (+ Intercrop, No Intercrop)	0.4/2 = 0.2 ha

Pasture management and measurement

Legume pastures in each crop sequence (Table 1) were established initially with full cultivation, and thereafter were expected to regenerate naturally. Seeding rates were 30, 20 and 50 kg/ha of Verano stylo, *Alysicarpus* and *Centrosema*, respectively. Following the crop phase in sequence B (Table 1), density of *Centrosema* seedlings of the new pasture phase was inadequate; areas were scarificed lightly and seed broadcast at 26 kg/ha.

Grass was controlled in initial establishment with Treflan at 2.8 kg a.i./ha, and two weed species very much taller than the pasture legumes were controlled subsequently with glyphosate applied with a rope-wick boom.

The strategy for fertilization of the croplands was to keep all nutrients non-limiting. The only elements ever shown to be deficient in the region are N, P, S and Zn, with deficiencies of the last two occurring only occasionally. Prior to the experiment the area had received a large quantity of single superphosphate (Table 2). It was judged that the residual effects of this plus a further 200 kg of single superphosphate/ha in 1981/82 obviated the need for further applications on the pasture in 1982/83 and 1983/84. Similarly, residual effects of K and micronutrients from before the experiment and from crop phases in the experiment were judged sufficient for the pasture phases (Table 2).

Table 2. Fertilizer applied (kg/ha) to the croplands area.

Period	Single superphosphate		K		Zn, Cu, Mo		N
1978-81	1010		90		+		
	Ley	Crop	Ley	Crop	Ley	Crop	Crop
1981/82	200	200	0	50	+	+	35
1982/83	0	300	0	50	0	+	V++
1983/84	0	400	0	50	0	+	V
1984/85	0	300	0	50	0	+	V

+ Indicates 10 kg/ha each of copper and zinc sulphates and 0.2 kg/ha sodium molybdate; all fertilizer was broadcast except for superphosphate on crops in years 1981/82, 1982/83, and 1984/85.

++ Variable N rates on subplots; no N on main area.

Pasture vegetation in the croplands was sampled at three times. In late April, near the end of the main green season (as identified in Figure 3, below), the yield and composition of the pasture vegetation (including crop, weed and intercrop) were measured using the BOTANAL technique (Hargreaves and Kerr, 1978; Tothill et al, 1978). Pastures were sampled a second time at the start of the main dry season (as identi-fied in Figure 3, below), when cattle were admitted, and a third time at the end of the main dry season, when cattle were removed. On these occasions, ten 0.5 m^2 quadrats were harvested in each ley area of the three legume treatments.

The natural pasture area was typical of vegetation of the region. Each half of the area was burned in alternate years during the main dry season.

Crop management and measurement

Although in some years there is substantial rainfall in November and early December, its reliability is too low for planting before mid-December. Early rains result in regeneration of pasture species which yield 1 to 3 t DM/ha by crop planting time in most years. Crops were planted without prior tillage into pasture killed with glyphosate sprayed 1-2 weeks earlier at 2 l/ha. Maize was sown in 1981/82 and 1983/84; an early-maturing grain sorghum had to be substituted in 1982/83 due to the very late arrival of planting rains. Rows were 75 cm apart. Maize populations were 50-60,000/ha and sorghum 100,000/ha.

Fertilizer applications are shown in Table 2. Nitrogen (ammonium nitrate) was banded on the surface. In 1983/84 and 1984/85, plots within the main crop received a range of N rates. In each legume species treatment, rates of 0, 25, 50, 75, and 125 kg N/ha were replicated twice on plots 15 m x 4 rows.

At planting, the 'no intercrop' treatment was sprayed with 1.8 l Dual-atrazine/ha to control both grasses and legumes. The 'intercrop' treatment received only Dual at 2.0 l/ha.

Grain yields reported (1983/84, 1984/85) were measured on 13 m lengths of the centre two rows of the N-treatment plots. Grain was oven dried and yields expressed on a 14% moisture basis. Stover dry weight was measured at the time of the second pasture sampling. Six 2.25 m^2 quadrats were harvested in each of the six 0.2 ha crop areas.

Cattle management

Block licks containing NaCl, P, S and urea were available to cattle on natural pasture; the same mix minus urea was available to animals grazing croplands. Cattle were sprayed for tick control six times per annum. Cattle were returned from croplands to natural pasture areas when sufficient rain had fallen to produce substantial new growth on the burned area, i.e. 30-40 mm of rainfall.

At the start of each ley grazing period there were four animals in each ley pasture cell (two 1.5 years old and two 2.5 years old) and four animals grazing natural pasture (same age mixture). At the end of this period the older animals were replaced by yearlings. The reported growth of the ley/natural pasture group during the main green season is for the animals remaining in the trial only.

Cattle were weighed without fasting on the occasions indicated in Figure 3. Observations were made on grazing behaviour with regard to pasture and stover areas for one day every 2 weeks. Note was taken of the location of each steer and what it appeared to be eating at 15 minute intervals between 0730 and 1730.

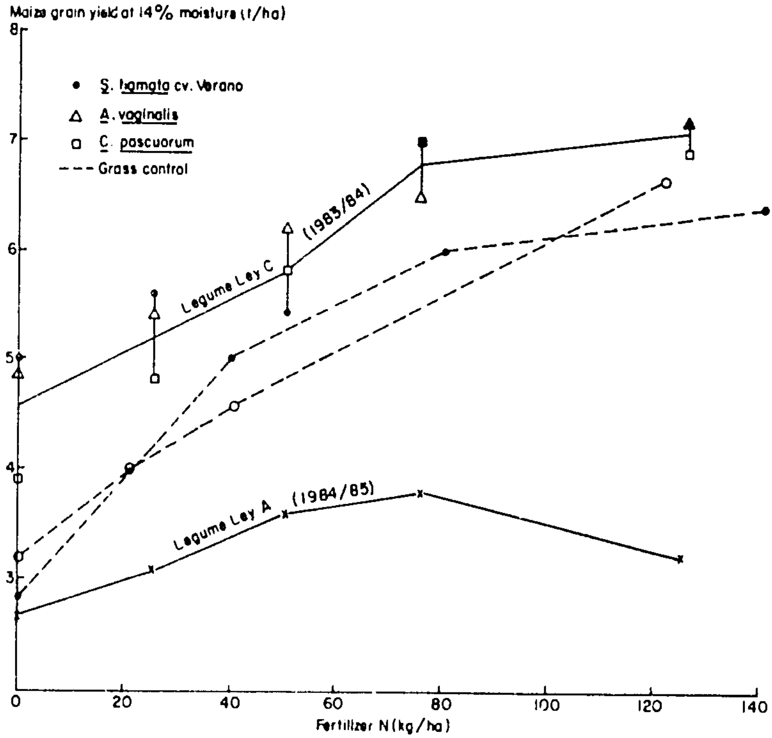
RESULTS AND DISCUSSION

Crop production

In only 2 years of the four could the effect of the 2-year ley on a succeeding crop be assessed (Table 1, sequences A and C). The 1984/85 season was unusually dry and yields were too low for the test crop bioassay for available soil N to be very informative (Figure 2). In 1983/84, water supply was ample, maximum yields were high and yields tended to increase linearly with fertilizer applications up to about 100 kg N/ha (Figure 2). To aid estimation of the N contribution of the legumes to the crop, data of two control grass treatments from other experiments have been included in Figure 2. Soil type and maize variety were the same as in the main experiment, and although grown in different years, maximum maize yields at the highest N rates were sufficiently similar (6.5-7 t/ha) to provide a helpful comparison with the effects of the legume leys.

An approximation of the fertilizer value of the legume ley can be obtained from Figure 2 as the amount of N that was needed on maize following grass to yield the same as maize following legume ley but without N fertilizer. This was

Figure 2. *Response in grain yield to added nitrogen following legume leys in two sequences identified in Table 1.*



about 40 kg N/ha for the 1983/84 crop. The pasture that provided this effect had a dry-matter yield of 6.6 t/ha in the first year, 90% of which was legume (Ley 1, sequence C); Ley 2 (second year) yielded 5.8 t/ha, 57% of which was legume (Table 3).

Differences in maize yield after Verano stylo and *Alysicarpus* leys were small (Figure 2). However, after *Centrosema*, maize yield without N fertilizer was about 20% less than after the other two legumes (Figure 2), even though yields of legume in the preceding *Centrosema* ley were as high or higher than in the other two leys (Table 3). If this difference is real, this is particularly puzzling since the N concentration in *C. pascurorum* is higher than in the other two legumes (data not shown).

Table 3. Yield and composition of leys sown to *Stylosanthes hamata* cv. Verano, *Alysicarpus vaginalis*, and *Centrosema pascuorum* in both first and second years in two crop-ley sequences (Table 2). (Forbs other than the three legumes are not reported and account for the deviation of totals from 100%.

Sown legume species		Sequence C Ley 1	Sequence C Ley 2	Sequence A Ley 1	Sequence A Ley
Stylosanthes	Dry weight (t/ha)	6.6	5.8	4.7	7.4
	S. hamata (%)	85	44	62	36
	A. vaginalis (%)	10	13	25	25
	C. pascuorum (%)	0	0	0	0
	Grass (%)	2	39	6	38
Alysicarpus	Dry weight (t/ha)	4.8	6.2	5.5	7.1
	S. hamata (%)	10	39	0	2
	A. vaginalis (%)	85	32	77	12
	C. pascuorum (%)	1	0	0	0
	Grass (%)	0	29	22	85
Centrosema	Dry weight (t/ha)	7.1	6.5	5.1	9.3
	S. hamata (%)	3	24	1	6
	A. vaginalis (%)	3	23	15	15
	C. pascuorum (%)	72	22	77	70
	Grass (%)	0	29	1	8

The results of these 2 years raise more questions than they answer. Clearly large differences in benefits can occur, but what is the frequency distribution of benefits among years? Benefits to unfertilized maize yields in the 'good' season of 1983/84 were about two-thirds those of a one-year, ungrazed, pure legume sward reported by McCown et al, (1985) and about half of the highest we have measured following pure ungrazed swards. To what extent are differences due to effects of grazing or due to effects of grass being present? In the next phase of this study, a much larger sample of years will be obtained. At the same time, quantification of rates of mineralisation, degree of immobilisation due to the presence of grass and loss rates as affected by soil type and water climate will be monitored in closely related studies.

Animal production

Trends in cummulative liveweight change of cattle for a 3-year period averaged over the three legume species are shown in Figure 3. Animals grazing continuously on natural pasture gained an average of 93 kg per annum, whereas those on croplands during the dry season averaged 123 kg. To assist analysis of these differences, years in Figure 3 have been divided into seasons: main dry (Dm), when animals were grazing croplands; early green (Ge), a period of erratic rainstorms when cattle on croplands return to natural pastures; main green (Gm), the period of weight gain on natural pastures; and early dry (De), a non-gain period on natural pasture prior to availability of croplands.

Cattle gained an average of 456 g/head per day when grazing croplands in the main dry season, 705 g more than those that remained on grass pasture (Table 4). Part of the advantage gained by cattle in the croplands during the main dry season was lost in other seasons. In 2 of the 3 years in which cattle remained on the legume leys following more than a few millimeteres of rain in the early green season, weight loss was rapid (Figure 3). This was presumably due to intake suppression as a result of moulding (McCown et al, 1981). Losses that occurred in animals on the natural pastures were probably due to reduction in gut fill with the appearance of first green grass regrowth (McLean et al, 1983). Further weight advantages gained by cattle in the croplands were lost on natural pastures during the main green and early dry seasons (Table 4, Figure 3).

Figure 3. *Cumulative liveweight trends for cattle continuously on natural grass pasture and for cattle on croplands in the main dry season and on natural grass pasture the rest of the year. First rains (mm/day) each year is indicated by arrows. Seasons denoted by Dm (main dry), Ge (early green), Gm (main green), and De (early dry).*

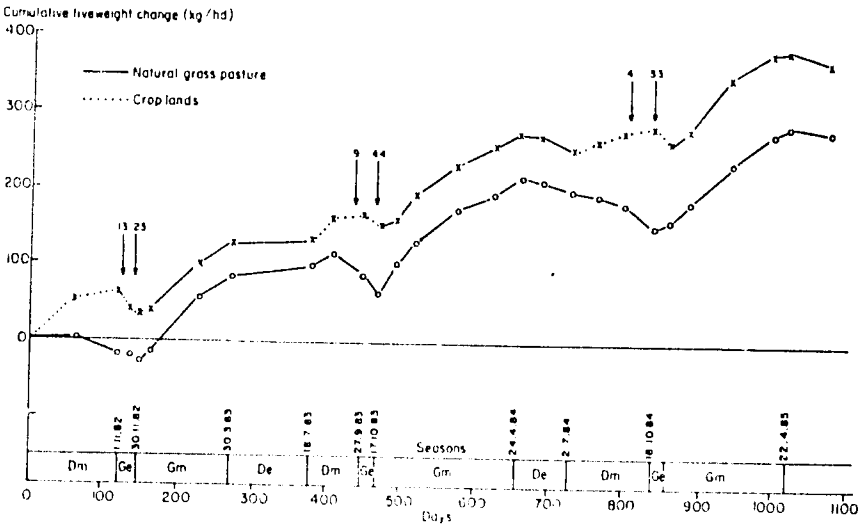


Table 4. Rates of liveweight change of cattle grazing (a) natural pastures the entire year and (b) native pastures in the green season and legume leys in the dry season (averages of three years).

	Duration (days)	Continuous natural pasture	Natural pastures + leys
		Liveweight change (g/hd/day)	
Dry season			
Early	90	-67	-171
Main	99	-249	+456
Green season			
Early	22	-393	-964
Main	159	+827	+733

Liveweight gains of animals grazing the three legume species treatments did not differ greatly except in the main dry season in 1984, when rate of gain of animals grazing *Alysicarpus* was much less than that of animals grazing the other two legumes (Table 5). This low rate of gain was associated with the lowest total legume (48%)/highest grass (52%) pasture composition in the experiment (Table 6). In the one season (1982) when the purity of the sown species was high in all paddocks (Table 6), rates of gain differed by less than 3% (Table 5). In subsequent years, interpretation in terms of differences in animal production between legume species is hampered by the mixing of legumes that had occurred (Table 3).

Table 5. Liveweight changes during the main dry season on four pastures.

	Year		
	1982	1983	1984
	--- Liveweight change (g/hd/day) ---		
Verano ley	+448	+559	+443
Alysicarpus ley	+449	+451	+235
Centro ley	+459	+541	+467
Natural grass	-168	-143	-238

The amounts of pasture dry matter available at the beginning of the main dry season ranged from 3.8 to 5.6 t/ha, comprised in most cases of more than 70% legume (Table 6). About 2 t/ha generally remained at the end of the period. Rate of disappearance per day was 7.3, 9.2, and 8.6 kg for the 3 years.

The nutritional contribution of stover would have been modest. Crop on one-third of the grazed area provided 0.3-0.5 t of stover per animal, much of which, although unmeasured, was not eaten. Quality of maize stover is normally low and the normally more valuable sorghum did not ratoon significantly in 1983. Time spent grazing maize stover declined from 13% at the beginning to 2% by the end of the main dry season. In 1983, time spent on sorghum stover declined with time from 15 to 9%.

Table 6. Yields and composition of croplands forage when cattle entered and when they left in three main dry seasons (Figure 3).

	Stover DM (t/ha)	Initial pasture DM (t/ha)	Proportion of legume (%)	Residual pasture DM (t/ha)
1982				
S. hamata		5.0	93	1.7
A. vaginalis		3.8	90	1.6
C. pascuorum		5.2	81	2.1
Mean	1.5	4.6	88	1.8
1983				
S. hamata		3.8	74	2.1
A. vaginalis		4.3	77	1.8
C. pascuorum		4.3	78	2.0
Mean	1.0	4.1	76	1.9
1984				
S. hamata		5.6	67	2.0
A. vaginalis		5.2	48	2.0
C. pascuorum	1.0	5.6	79	2.9
Mean		5.4	65	2.3

Botanical stability

Annual grass invasion: The third major objective of this study relates to the threat of invasion of legume leys by grass. Under conditions of low soil P and with grazing during the wet season (when grass is grazed preferentially), legume pastures in this environment have retained a high degree of purity for many years (Winter et al, 1985). However, under conditions of high P input and grazing deferred until the dry season, annual grass invaded and displaced Townsville stylo after a few years (Gillard and Fisher, 1978). Our hypothesis in the present experiment was that by using legume species that are more competitive than Townsville stylo, and with ley durations of only 2 years before cropping with nitrophilous crops which deplete available soil nitrogen levels (and when grass is 'eradicated' with herbicides), grass content of leys could be kept to a tolerable level.

Table 3 shows the changes in botanical composition from the first to the second year of ley in two crop sequences (Table 1). Ley 1, sequence C was the original pasture in which every effort was made to ensure high purity of the sown legume species. Legume contamination was only 10% and grass no more than 2%. By the second year, Verano stylo in the stylosanthes treatment had dropped from 85% to 44% and grass had increased from 2 to 39%. The proportion of alysicarpus in the alysicarpus treatment dropped from 85% to 32% due mainly to an increase in grass from nil to 28% and, of less consequence, an increase in Verano stylo from 10 to 39%. The proportion of Centrosema dropped from 72 to 22% due to an increase in grass from nil to 29% and invasion of both other legumes. Ley 2 in sequence C was succeeded by the maize crop in 1984 whose N response is shown in Figure 2.

Ley 1 of sequence A (Table 1) was sown without herbicides, and purity was lower than in sequence C. Initial foreign legume content, although quite high in stylosanthes and centrosema treatments, did not increase in Ley 2. Grass invasion varied dramatically among legume treatments. There was remarkably little invasion into centrosema. The pattern in stylosanthes was similar to that in sequence C. However in alysicarpus, grass content in Ley 1 was 22% which increased to 85% in Ley 2.

Legume regeneration: An opportunity to compare the abilities of the three legumes to re-establish pastures in the year following the crop occurred in sequence B (Table 2). In 1982 leys of the three species, over 80% of the leys consisted of the species sown (Table 7). Total dry-matter yields exceeded 5.5 t (Table 6). In the crop in 1983, Alysicarpus comprised a high proportion of both weed and intercrop vegetation (Table 7), even in stylosanthes and centrosema treatments. In 1984, ley pastures of alysicarpus and Verano established swards with acceptable amounts of the nominal legume without assistance. Centrosema failed to re-establish and the block was scarified lightly and re-sown; despite this, centrosema comprised only 12% of the yield at the end of the growing season (Table 7).

C. pascuorum is not easy to establish on bare soil. In contrast to the other two species, which have small seeds, the large radicle of this large-seeded species has difficulty penetrating even wet soil without counter-resistance on the seed by soil or mulch cover.

Perennial grass invasion: The perennial grass *Urochloa mozambicensis* cv. Nixon is very well adapted to this climate and, where it has been introduced, rapidly becomes a dominant component of permanent pastures where P fertilizer inputs are adequate. In this experiment, vegetation of border areas and fence lines was dominated by this species and received no special control measures. Although *U. mozambicensis* had been gradually increasing overall, the grass dominance, and particularly that of *U. mozambicensis*, increased dramatically between the 1984 and 1985 seasons (Table 8). Even allowing for the fact that the balance between grass and legume normally shifts toward legume as a season progresses, both the 93% total grass content of the new Ley 2 and the 56%

Table 7. Botanical changes in the pasture component of crop-ley sequence B. (Forbs other than the legumes indicated are not reported and account for the deviation of totals from 100%).

Sown legume species	Actual components	Percent by weight Ley 1982	Crop 1983	Ley 1984
Stylosanthes	*S. hamata*	84	11	36
	A. vaginalis	10	78	34
	C. pascuorum	0	0	0
	Grass	1	7	27
Alysicarpus	*S. hamata*	16	0	12
	A. vaginalis	80	91	64
	C. pascuorum	0	0	0
Centrosema	*S. hamata*	2	1	22
	A. vaginalis	1	32	30
	C. pascuorum	83	10	12*
	Grass	0	10	36

* Oversown in response to failure to re-establish naturally.

Table 8. Total dry matter and botanical composition of seedling vegetation early in the 1984/85 season (12 Dec 1984).

Treatment in 1984: 1985:	Crop/IC* Ley 1	Crop/No IC Ley 1	Ley 1 Ley 2
Total DM (t/ha)	1.4	1.5	2.2
Legume %	45	34	2
Annual grass %	42	8	93
U. mozambicencis %	8	56	3

* Intercrop of pasture vegetation.

U. mozambicensis content of half of Ley 1 are alarming. The reason for the very much higher *U. mozambicensis* content in the 'no intercrop' treatment is not clear, but it is not accounted for by differences in *U. mozambicensis* content in the previous ley phase (data not shown).

In the present study, crop height was dramatically depressed in patches that had been dominated by *U. mozambicensis* in the previous ley. This was presumably due to a much greater immobilisation of soil N. Considering the apparent rapid increase in the proportion of *U. mozambicensis*, the implications on system performance and the difficulty of selectively eliminating this species, it was decided to terminate the study. This was done in time to plant a uniform crop of maize in the 1985 season, accompanied by an intensive weed control program. It is planned to recommence the study when the *U. mozambicensis* problem is under control, and to manage the area in the future to minimise access of this species.

For a system in which a pasture or forage crop displaces a grain crop to be economically feasible in either Australia or Africa the synergistic benefits have to be substantial. A gross comparison of production of the ley system and that of continuous cropping and permanent grazing is made in Table 9. In spite of productivity benefits to the crop, total maize grain yields in the ley system are estimated to be about half that of a continuous cropping system. Cattle liveweight gains were 360 kg (22%) higher than on continuous natural pasture grazing.

At this stage, simplistic economic analysis of the differences is likely to be misleading. In the first place, there is evidence that in neither Africa or Australia would such ley pastures be used for fattening cattle. In northern Nigeria, Fulani pastoralists tend to use Verano stylo fodder banks in the dry season to ensure survival of vulnerable animals rather than for production (von Kaufmann, personal communication). In Australia preferred use might be for weaners - to ensure good growth rates during weaning and training in the confinement of small paddocks. In both cases the monetary benefits are substantial, but more difficult to quantify than liveweight of slaughter cattle.

Table 9. Comparison of the total annual production of three systems.

	Maize grain		Cattle	
	Area (ha)	Yield (t)	Area (ha)	Wt gain (kg)
Continuous cropping	3.6	10.8*	-	-
Continuous natural pasture grazing (18 steers)	-	-	180+?	1670
2:1 ley-crop rotation	1.2	5.5	180+3.6	2030

* Yield of maize following a crop and with no nitrogen fertilizer assumed to be 3 t/ha.

CONCLUSION

In the Australian context, where it can be presumed that it is unprofitable not to remedy non-nitrogen nutrient deficiencies in cropland, depreciation of the legume benefits by grass invasion of well fertilized leys may be the most serious threat to success of this hypothetical system. (In the next phase of this study much greater attention will be paid to the dynamics of weeds.)

In the African context, problems of restricted availability and high costs of supplying non-nitrogen fertilizer seem inescapable, and the implications of phosphorus deficiencies on both crop and animal enterprises of the legume ley system need to be quantified. With regard to crops, both legume N production and the response of the cereal crop to the increased N supply are sensitive to

P supply. Research on these interactions with P supply and the further interaction with legume species was recently started at Katherine, and collaborative research is planned in Kenya and northern Nigeria. With regard to animals, the degree to which P fed as mineral supplements can compensate for low fertilization of legume pastures is currently under study at Katherine and collaborative research is planned in northern Nigeria.

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FODDER BANKS: FOR PASTORALISTS OR FARMERS

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ABSTRACT

In West Africa, communal grazing usually comprises poor quality grasses which are burnt-off during the dry season. Legume fodder banks can provide high-quality feed during the dry season, and are gaining acceptance among settled pastoralists in the subhumid zone. A well managed fodder bank of *Stylosanthes* spp. of about 4 hectares can provide protein supplements for 15 to 20 cattle during the dry season. Growing forage legumes also increases yield of subsequent crops. The ability of forage legumes to benefit both crops and livestock will be increasingly important in areas where population pressure is increasing.

INTRODUCTION

Transhumant cattle move across large areas of tropical West Africa in search of better-quality forage, while cattle owned by settled pastoralists are restricted to forage available within herding distance of the home base. The natural herbage is mainly grasses, which are nutritionally adequate for only 3 - 4 months in a year (Mohamed-Saleem, 1984). Crop residues contribute significantly to the dry-season diet of cattle of both nomads and settled pastoralists. About 20% of the Nigerian subhumid zone (SHZ) is cultivated at present, and this proportion is likely to increase rapidly with the growing population (Bourn and Milligan, 1983; Putt et al, 1980).

Pastoralists recognise the need for better pasture as a long-term solution to nutritional shortfalls, especially after the recent sharp price increases and difficulties in obtaining agro-industrial byproducts. But settled pastoralists face the following constraints to forage development:

1. Shortage of labour - all extra labour is required for subsistence cropping.
2. Lack of mechanical expertise (not even animal power implements)
3. Little security of tenure on land, hence no long-term commitment to land development. Use of land is controlled by arable farmers who generally have no direct interest in cattle production.
4. Communal grazing by pastoralists.
5. Indiscriminate annual bush burning.

Fodder banks (concentrated units of forage legumes established and managed by pastoralists near their homesteads) are gaining acceptance among pastoralists in the SHZ as a means of providing additional protein for sedentary cattle during the dry season.

Floral and edaphic changes that are evident under fodder banks and the increased yields of cereals when such areas are reverted to cropping (Mohamed-Saleem, 1984) also suggest serious considerations of a role for fodder banks in cropping systems. Tropical soils need to be fallowed to maintain their productivity, even at high levels of fertilizer input (Young and Wright, 1980). Thus, growing legumes on land that would otherwise be fallowed might be appropriate in situations in which increasing population pressure has shortened fallow periods.

This paper outlines the principles and practices of fodder-bank establishment and management in the SHZ, and summarises data that indicate the benefit of fodder banks to subsequent crops.

FODDER BANKS AS A SOURCE OF PROTEIN FOR LIVESTOCK

Forage intake by ruminants is reduced severely when the crude protein (CP) content of the herbage is less than 7% (Crowder and Chheda, 1982). Although selective grazing can increase the nutrient intake of the animals, most of the herbage available during the dry season comprises physiologically mature grasses of low nutritive value. Including forage legumes in the diet would be of value, in that they tend to contain more protein than grasses at comparable stages of growth.

Various exotic forage legumes have been introduced into Nigeria and native forage legumes are being collected, in attempts to find species that can provide high-protein feed for livestock. A number of species have shown promise, e.g. *Stylosanthes guianensis* cvs Cook, Schofield and Endeavour, *S. hamata* cv. Verano and Townsville stylo (Agishi and Asare, 1980; Agishi, 1982). However, because of the lack of extension work on forages, the forage production technology developed on research stations has not been adopted by traditional livestock producers.

The ILCA SHZ Programme has formulated guidelines for the establishment and management of stylo-based fodder banks:

1. Fence a block of about 4 hectares.
2. Prepare the seed-bed by confining the herd over-night in the area prior to the onset of the rains.
3. Broadcast scarified seeds.
4. Control fast-growing grasses by early grazing.
5. Defer grazing until the dry season to allow the forage to grow.
6. Selected animals graze the fodder bank 2.5 hours per day during the dry season.
7. Ensure sufficient seed drop and stubble for regeneration in the following season.

The fodder bank is sited close to the pastoralist's homestead to prevent animals grazing the fodder bank during the growing season. The land area for fodder banks was determined on the basis of the average number of pregnant and lactating cows in herds, i.e. those animals that are likely to benefit most from improved feeding. In the SHZ of Nigeria the average herd size is about 50 cattle, of which 15 to 20 are cows. Otchere (1984) found that feeding 1 kg of cotton seed cake (30% CP) per day maintained the body weight and productivity of these animals throughout the dry season. With a potential dry-matter yield of 4 to 5 t/ha from stylo (12% CP) a 4 hectare fodder bank would provide enough supplementary feed for the selected animals for 6 months.

A fodder bank is meant to provide protein supplementation and hence the management practices are geared to maximising the proportion of legume in the fodder bank at the end of the growing season. The fodder bank should also last for several years in order to cover the costs of establishment. Gardner (1984) found the following factors to be important for long-term persistence of stylosanthes:

1. Demographic characteristics, in terms of germination, establishment, seedling survival and plant longevity and seed input, dormancy and dispersal;
2. Grazing pressure;
3. Soil fertility and fertilizer application;
4. Nitrogen output to the soil/plant system;
5. Other species in the pasture; and
6. Time of first rains.

Stylosanthes hamata fodder banks managed by ILCA researchers have remained productive for several years (Table 1), and the proportion of stylo in the herbage has remained relatively constant. Under correct management, the amount of stylo seed in the soil increases each year (Table 2), and this seed reserve ensures the regeneration of the fodder bank even if some seedlings are killed by periods of drought at the beginning of the rainy seasonn. Strategic grazing early in the growing season controls the growth of other forage species and helps to maintain a high proportion of stylo in the fodder bank.

Table 1. Total dry-matter yield and percentage stylo in fodder banks at five locations under different management.

Management		Age of fodder bank (years)				
		1	2	3	4	5
Researcher managed - researcher executed						
-K'Biri -	(a)*	6824	7350	4748	6546	
	(b)	56.0	55.4	[illegible]2.0	61.0	
Researcher managed - pastoralist executed						
-K'Biri -	(a)	6101	4191	5742	5006	4789
	(b)	60.1	68.9	62.6	52.0	53.0
Pastoralist managed - pastoralist executed						
- Kachia -	(a)	7111	5278			
	(b)	68.0	64.5			
Pastoralist managed - pastoralist executed						
- Kontagora -	(a)	6120				
	(b)	52.2				
Pastoralist managed - pastoralist executed						
- Ganawuri -	(a)	7900				
	(b)	59.6				
Researcher managed - pastoralist executed						
- Abet -	(a)	4281	4900	5278	5469	4789
	(b)	58.4	63.0	64.5	70.1	71.0

* (a) Total dry-matter yield (kg/ha).
(b) % weight of stylo.

Table 2. Number of seeds/m^2 recovered prior to the beginning of rains from fodder banks under different management practices.

Management	Year 1	2	3	4	5
Researcher managed-researcher executed	941	2839	2745	3102	
Researcher managed-pastoralist executed	1328	2160	648	270	
Pastoralist managed-pastoralist executed	1529	1372	1824		
Pastoralist managed-pastoralist executed (mismanaged)	27	Resown	46		

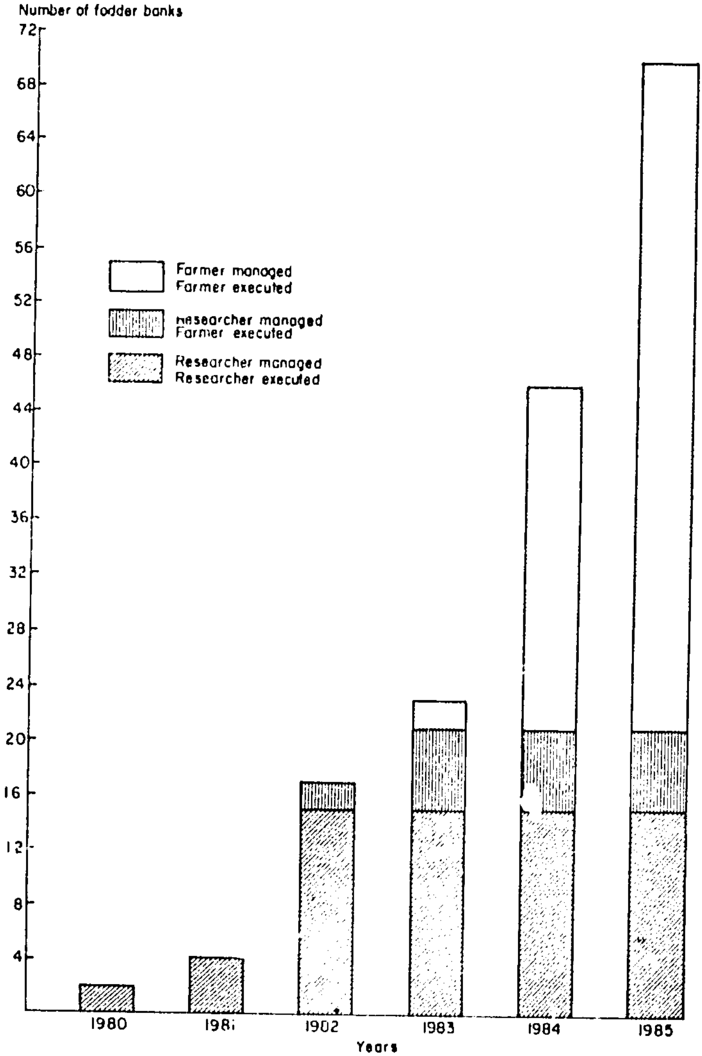
Grazing studies on researcher-managed fodder banks (Bayer, 1984) showed that grazing for 2 or 4 hours per day resulted in a highly significant reduction in liveweight losses despite overstocking. There were also indications of a reduction in effective grazing time on free range if animals had access to a fodder bank.

The productivity, legume composition and persistence of fodder banks have been found to vary with changes in management practices introduced by the pastoralists to suit their convenience. Some pastoralists would not confine their cattle to the fodder bank area in order to prepare the seed bed by trampling as it interfered with the time of manuring crop fields. Early grazing to control grass growth in the fodder banks was not practised by some pastoralists because they believed that grazing on freshly manured fields increased the risk of worm infestation, or because they thought that the animals would damage the stylo seedlings. In these cases the legumes in the fodder bank were smothered by tall grasses. Untimely and prolonged grazing, overstocking, and fire probably caused deterioration of some fodder banks after the first year. *S. guianensis* cv Cook is a perennial and flowers at the beginning of the dry season, and pastoralists had to resow in the second year when cattle were allowed to graze before seed was set.

It has been difficult to persuade pastoralists to restrict the use of fodder banks to the most responsive animals in the herd, i.e. pregnant and lactating cows, because they believe that the weakest animals in the herd are most in need of higher-quality feed. Although stocking rates higher than that recommended in the guidelines did not affect seedling emergence and proportion of *S. hamata* cv. Verano in the fodder bank, it reduced the seed reserve considerably, probably due to animals licking seed from the ground at the end of the dry season. However, repeated overstocking tends to reduce the productivity of the fodder bank after 2 to 3 years. Pastoralists established fodder banks for a number of reasons, including land aquisition and survival feeding, and the number of fodder banks in the subhumid zone of Nigeria increased from only 2 in 1980 to 70 in 1985 (Figure 1). More will be developed in the second livestock development project.

In the SHZ of Nigeria pastoralists are generally landless. However, a relationship between cropping and livestock enterprises has been observed (Bourne and Milligan, 1983), in that cattle population density increased with cultivation intensity up to a level at which 50% of the land was under cultivation. Pastoralists were found to settle amongst the arable farming community for many reasons, the most important of which are access to land for cropping and crop residues. As the farming population increases, access to land may become difficult for the pastoralists, as land is preferentially allocated to people more closely related to the farming community. However, even in intensively cropped areas, a farmer normally owns more land than he cultivates. Some pieces of land close to the dwelling are continuously cultivated in preference to others in distant locations (Powell, 1984).

Figure 1. *Number of fodder banks at various levels of management in Nigerian subhumid zone, 1980–85.*



EFFECT OF CROPPING ON SOIL

In the savannah region, of which the SHZ is a part, intensification of agricultural production, such as continuous cropping, complete land clearing and mechanised farming, leads to accelerated soil erosion resulting in a reduction in the nutrient content of the surface soil and in its ability to retain nutrients. It also becomes coarser in texture. Savannah soils are usually subjected to exceptionally high-intensity rains and kinetic energy loads during the wet season (Kowal and Kassam, 1978). A fast-growing legume cover crop would protect the soil and help to reduce soil erosion.

PROBABLE BENEFITS FROM STYLO TO CROP PRODUCTION

The legume component in the fodder bank increases soil N through fixation of atmospheric N and decay of root nodules and by increasing the proportion of nitrifiable N (Vallis and Gardner, 1984). This encourages the establishment of nitrophilous species (Gardner, 1984), resulting in changes in the botanical composition of the fodder bank. The plant composition of a 4-year-old fodder bank of *S. hamata* cv. Verano at Kachia grazing reserve is given in Table 3.

Maize was grown on land that had been under fodder banks for 1 to 3 years to assess the amount of N made available by the legume. Maize was also grown on adjacent land that had either been fallowed or had been continuously cropped for 3 years. The grain yield of maize on land that had been under stylo was significantly higher than that of maize on continuously cropped land (Figure 2). The yields of maize on land that had been fallowed or under stylo were compared with the N-response curve of maize grown on continuously cropped land, to give an indication of the amount of N made available by the previous cropping treatments (Table 4). Growing *S. guianensis* for 2 years gave the largest increase in apparent N availability of 100 kg N/ha. However, even with increasing

Table 3. Frequency distribution (%) of major grasses in a 4-year-old *S. hamata* cv. Verano fodder bank, Kachia grazing reserve.

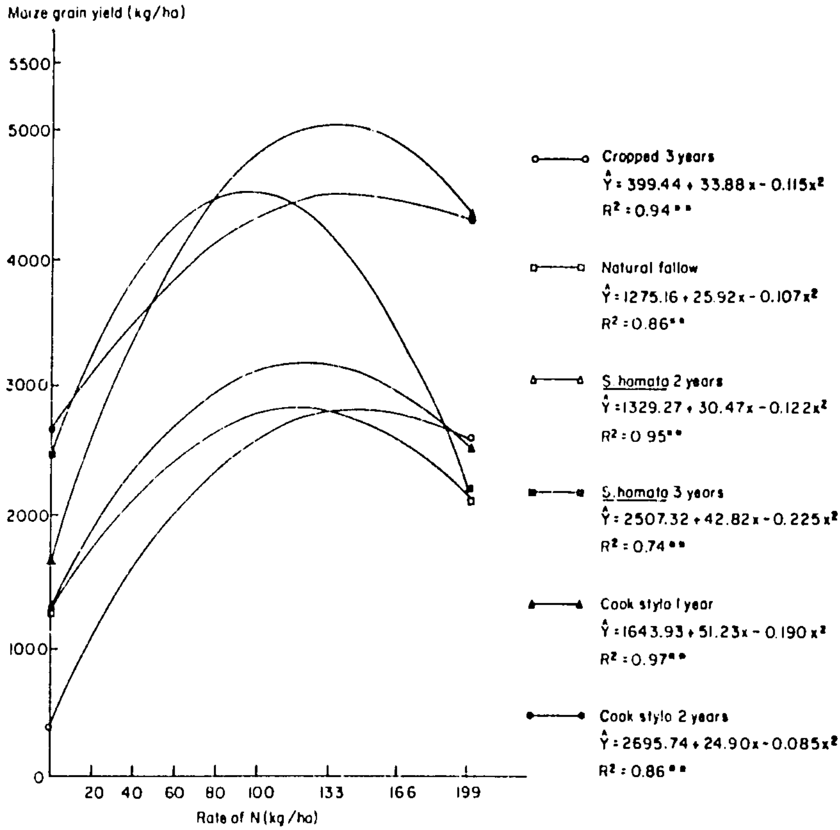
Species	Natural Vegetation	Fodder bank
Andropogon spp.	6.2	13.3
Brachiaria spp.	8.3	
Digitaria spp.	0.8	
Hyparrhenia spp.	11.4	16.1
Louditia spp.	40.7	4.0
Panicum spp.	0.8	
Paspalum spp.	1.4	0.4
Pennisetum spp.		0.5
Setaria spp.	0.6	0.8
Others	24.4	5.6
Legume		
S. hamata cv. Verano		59.3

rates of N application the yield differences persisted, and these differences could only have been due to factors other than N accretion in the soil.

Differences were observed in bulk density, water infiltration rates, water-holding capacity, and gravel, organic-matter and N contents among the soils under the different cropping treatments (Table 5 and Figure 3). However, the physical properties of the soil were not monitored continuously and some of these differences may have been due to inherent variability of the soils.

The results indicate that experiments should be conducted to assess the influence of forage legumes on the physical properties of soils. It is possible that the ramification of the stylo root system and the vegetative cover, which would reduce soil erosion, had effects on the bulk density and the gravel percentage of the soil. As can

Figure 2. *Effect of N application on grain yield of maize following different land-use patterns, Kurmin Biri, 1983.*



be seen in Figure 4, there is a negative relationship between the water-holding capacity and the gravel content of the soil. Blondell (1965), in Senegal, found that sorghum grain yields increased by 600 kg/ha for each reduction in bulk density of 0.10 g/cm^3.

A preliminary observation using soil splash traps showed that the loss of soil during the growing season was considerably less from soil that had been under stylo than from soil that had been fallowed or cropped continuously (Figure 5).

Table 4. Grain yield of maize without N fertilizer and calculated amount of N contributed by previous cropping history.

Cropping history	Maize grain yield at zero N (kg/ha)	N contribution[1] (kg/ha)
Cropped 3 years	461	
Natural fallow	1275	30
S. hamata 2 years	1369	32
S. hamata 3 years	2507	90
S. guianensis 1 year	1643	44
S. guianensis 2 years	2696	100

1. Amount of N required on cropped soil to give yield equivalent to that at 0 N under alternative cropping history.

IMPLICATIONS IN THE CROP-LIVESTOCK PRODUCTION SYSTEMS IN THE SHZ

Due to its long growing period and high rainfall, the SHZ offers great potential for agricultural expansion. However, the favourable climatic conditions cannot be fully exploited unless soil fertility is improved and erosion controlled. The reduction in tsetse infestation by using pesticides and controlling its habitat had led to an increase in the human and livestock populations and this will further increase pressure on land.

Powell (1984) observed that farmers in the SHZ are gradually adopting high-energy crops such as maize in preference to millet and sorghum. One of the factors that contributed to this change was the availability of chemical fertilizers. Although fertilizer(s can replace nutrients and meet crop requirements, their efficiency is reduced if

Table 5. Preliminary data on some soil physical properties for different experimental sites, Kachia grazing reserve.

	Cropped soil	Fallow soil	Hamata soil 2 yrs	Hamata soil 3 yrs
Gravel content (g/100 g) in 0-10 cm depth				
		58 ± 3	21 ± 9	12 ± 8
Particle size distribution (%) of fine earth fraction				
Coarse sand		35	21	34
Fine sand		37	43	43
Silt		14	17	11
Clay		14	19	11
Soil bulk density (g/cm^3)				
	1.75	1.61	1.54	1.42
Available water holding capacity (g/100 g)				
		7.3	10.6	10.2
Field moisture capacity (g/100 g)				
		10.4		18.5
Organic matter content (%) values corrected for gravel				
		1.04	1.76	2.72

Measurements carried out by Dr. P.N. Vine, University of Ibadan.

the soil structure is weak and is prone to erosion and run-off. To maintain a favourable structure of the major soil types in the SHZ, Young and Wright (1980) recommend rest

Figure 3. *Water infiltration rates (mm/hour) at some experimental sites at Kurmin Biri.*

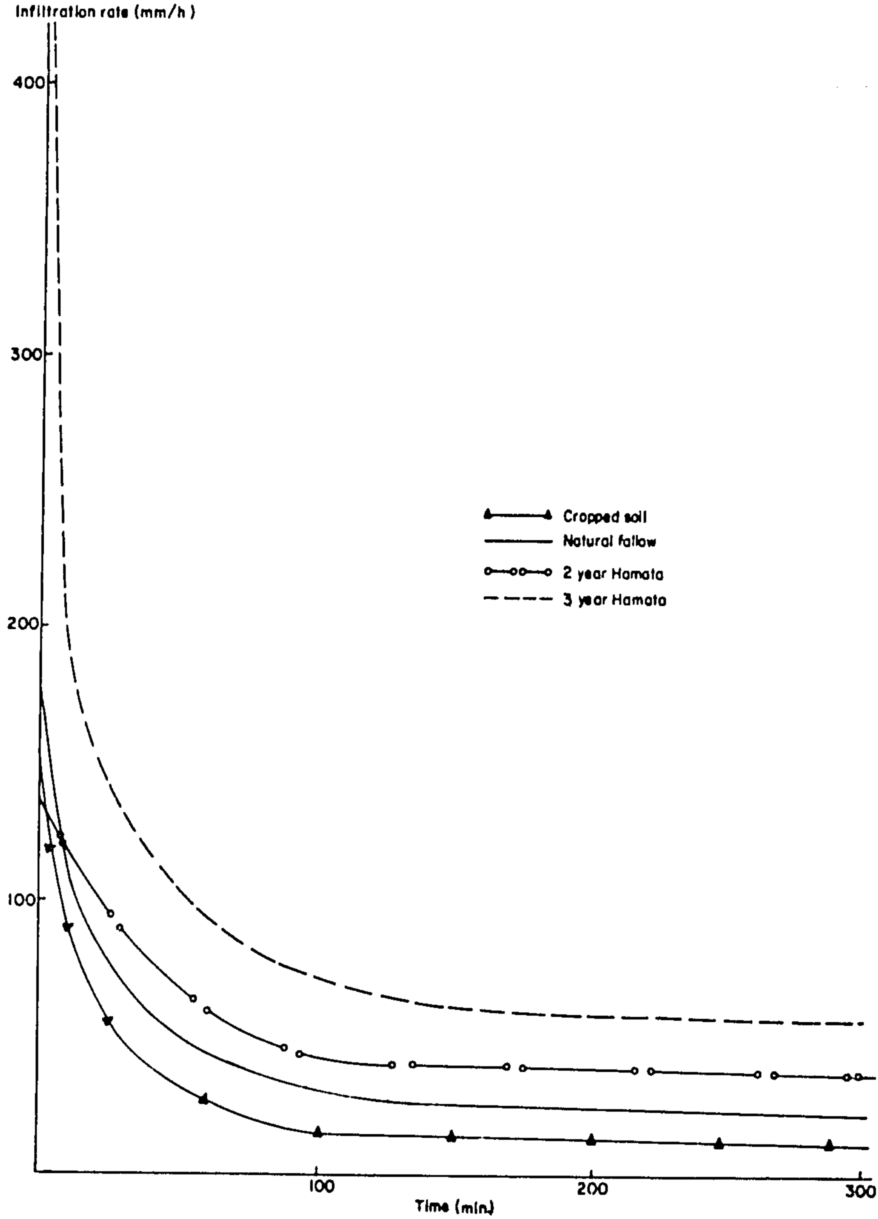
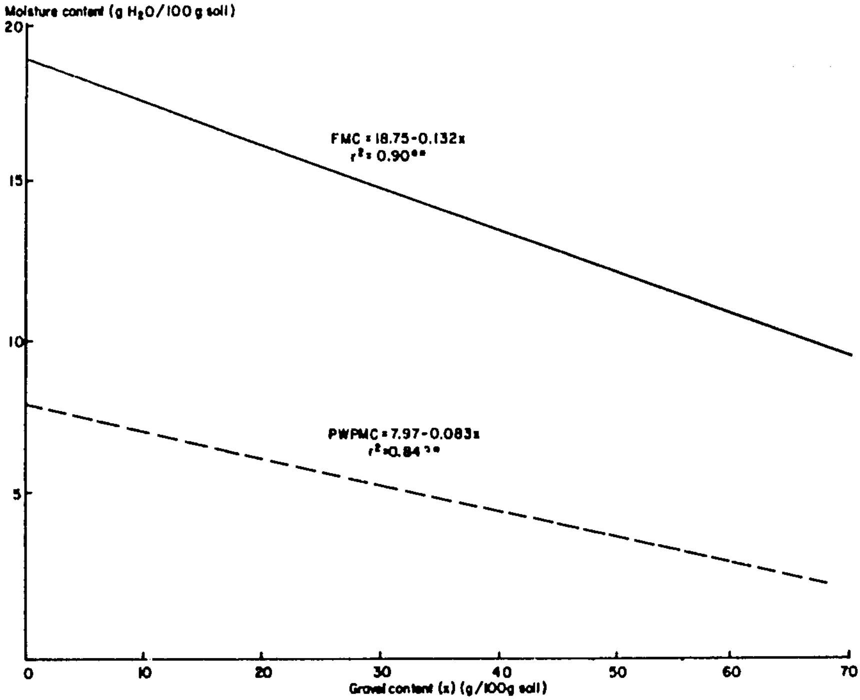


Figure 4. *Relationship between field moisture capacity (FMC) and permanent wilting point moisture content (PWPMC) with gravel content in soil.*

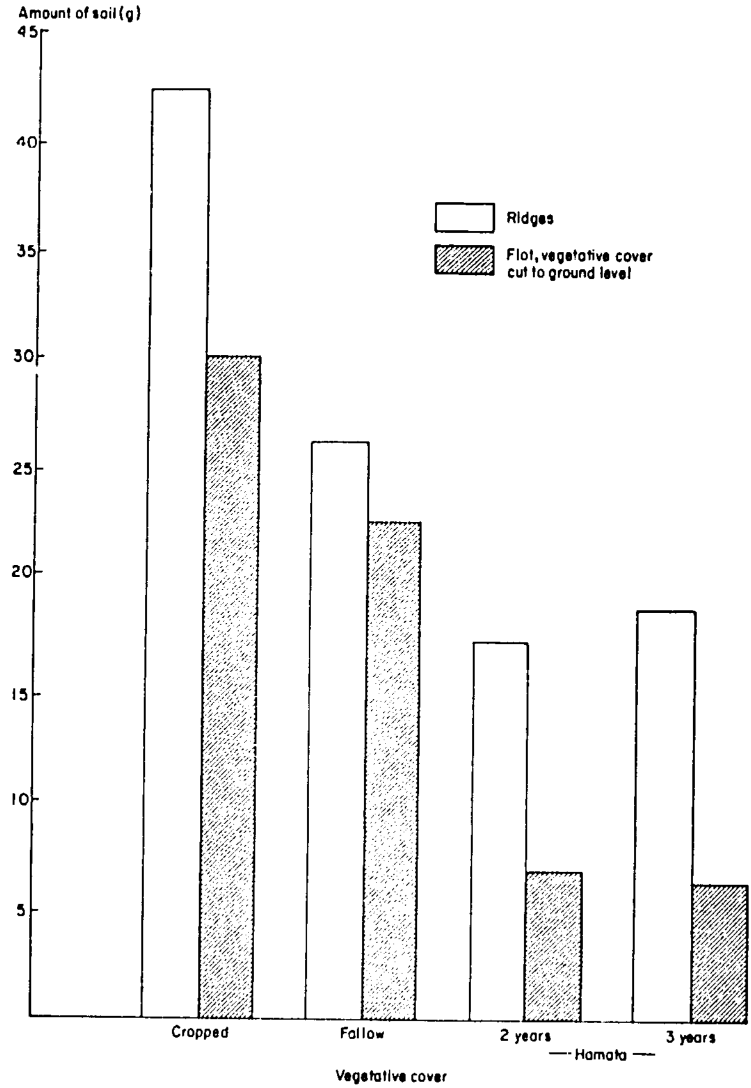


periods by reverting to natural vegetation for 1 year in 4, 3 years in 5 and 4 years in 5 for high, intermediate and low input levels, respectively.

Introducing a fast growing legume such as *Stylosanthes* spp. into the cropping system, which will occupy the required rest period, could provide more benefit to the crops than a natural vegetation.

Techniques to fit forage legumes into cropping systems are available (Mohamed-Saleem et al, this volume). Farmers who do not own livestock may also benefit from the legume if land is leased to pastoralists for the establishment of fodder banks.

Figure 5. *Total amount of soil collected in splash traps (78 cm rimmed funnels) during one growing season after ridging or vegetative cover cut to ground level*



CONCLUSIONS

The crop and livestock production potential of the SHZ can only be realised through the improvement of soil fertility and stability. Data show that the yields of cereal crops are higher on land that has been under forage legumes such as *S. hamata* than on land that has been fallowed. The forage legume also provides good-quality feed for livestock that could offset deficiencies in natural herbage, and pastoralists in the SHZ of Nigeria are showing interest in the use of fodder banks. The dual roles of forage legumes in benefiting both crops and livestock need to be exploited to increase agropastoral production in the subhumid zone.

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MINERAL STATUS IN SOILS, PLANTS AND ANIMALS OF THE BUTANA SEMI-ARID REGION OF THE SUDAN

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ABSTRACT

A nutritional survey was conducted by collecting soils, plants and blood samples in the Butana region of Sudan. The samples were analysed for major and minor elements. Data obtained were compared with established standards used for assessing nutrient status of soils, plants and animals. Results indicated that available macro- and micro-nutrient levels in Butana soils are adequate for normal pasture and animal growth and development. The authors recommend continued monitoring.

FORAGE POTENTIAL OF SOME NATIVE ANNUAL TRIFOLIUM SPECIES IN THE ETHIOPIAN HIGHLANDS

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ABSTRACT

The intraspecific variability of 34 accessions of *Trifolium tembense* from the Ethiopian highlands was studied. The effects of planting and harvesting dates and phosphorus application on the dry-matter yield, seed production, leaf tissue mineral contents and forage quality of nine native and three introduced clovers were examined.

Marked genetic variability was found both within and between the *T. tembense* accessions. The soil characteristics of the site of origin did not appear to have imposed any ecotypic variation. Planting the clovers in March, during the short rainy season, extended the growing season and gave higher yields than planting in June, during the long rains. P fertilization substantially increased both dry-matter and seed yields but had little effect on forage quality.

INTRODUCTION

There are 240 to 300 clover species of the genus *Trifolium* distributed around the world, and clovers are ubiquitous in natural grasslands in cooler climates (Evans, 1976; Allen and Allen, 1981). Although clovers rank second in forage productivity and feeding value to *Medicago sativa* in western countries, few *Trifolium* species are cultivated due to their recent domestication (Davies and Young, 1967).

While the Mediterranean region is the primary centre of diversity of clovers, there are a number of secondary centres of diversity in Africa, including central Ethiopia, Somalia, Tanzania and Kenya (Zohary, 1972; Thulin, 1982).

Forty *Trifolium* species are reported to be found in sub-Saharan Africa, of which about 25% are endemic to Ethiopia (Gillet, 1952; Thulin, 1982). About two-thirds of the clover species in Ethiopia are annuals and the remainder are perennials; biennials are not found in Ethiopia.

Livestock are important in subsistence agriculture, providing draught power, meat, milk, hides and dung for fuel and fertilizer. However, there are marked constraints to production, the most important being insufficient forage and poor forage quality, particularly during the dry season. During this period animals are mainly grazed on marginal lands and are fed cereal straw. Due to the current lack of importance of planted fodders in the prevailing subsistence farming systems of highland Africa, clovers are little exploited. There are, however, a number of ways in which they can be used to provide more and better-quality feed during the dry season.

Clovers grow rapidly when the growing conditions are favourable and produce a large amount of dry matter. This can be conserved as hay, which can be used to increase the quality of straw-based diets and to overcome seasonal feed shortages.

Some species grow naturally in valley bottoms which are not cultivated due to seasonal waterlogging. Thus they can be managed to increase forage production without competing with food crops for land. Some of the African clovers are adapted to acid and low-P soils (Norris, 1965; Andrew, 1976).

Similarly, clovers can be grown on land that would otherwise lie fallow as part of a crop rotation system. Their ability to fix atmospheric nitrogen will help to improve the fertility of the soil and thus increase the yields of succeeding crops. Large tracts of land are fallowed each year in Ethiopia.

Forage legumes also generally contain a large proportion of crude protein, and are thus a source of high-quality feed for livestock.

Studies were conducted in the Ethiopian highlands to describe, evaluate and screen some annual *Trifolium* species for their forage potential. The details of the work are published elsewhere (Akundabweni, 1984).

MATERIALS AND METHODS

The experiments were conducted on a low-P (1 ppm) Vertisol with a pH of 6.0 at ILCA headquarters. The site is at 2370 m a.s.l. and receives 1250 mm average annual rainfall. The mean annual temperature is 15.5 ^{o}C.

Experiment 1

Germplasm of *Trifolium tembense* was collected in 1982 from along four axes in the Ethiopian highlands:

1. Northeast from Addis Ababa (AA)
2. Southeast from AA
3. Southwest from AA; and
4. West from AA, plus the southeastern region.

The exploration design was based partly on the work of Krajina (1977). Collections were made from a few plants at each site. A soil sample was collected from each collection site and analysed for P and organic-matter contents and for pH.

Thirty-four accessions were selected from the germplasm collection, and seeds were sown in disposable polythene tubes in a screen-house at the beginning of June 1983. The plants were transplanted into the field at Shola, near Addis Ababa, on 26 July 1983. Each accession was space-planted in 4-m rows, with two replicates in a randomised complete block design. Interrow spacing was 40 cm.

Experiment 2

In 1982 an experiment was conducted to examine the dry-matter accumulation of the two annual clovers that are most common in the Ethiopian highlands, *T. tembense* (ILCA 6278) and *T. rueppellianum* (ILCA 5791) and two introduced clovers, *T. fragiferum* (ILCA 6280) and *T. resupinatum* (ILCA 7022) during the main cropping season.

The experiment was planted on 7 June 1982 in a randomised complete block design with four replicates. There were three plots of each species per replicate, with the plots consisting of five 4-m rows with interrow spacings of 40 cm. The seeds were scarified before planting, and were sown at 9, 8, 5 and 5 kg/ha for *T. rueppellianum, T. tembense, T. resupinatum and T. fragiferum*, respectively, these rates giving roughly the same number of seeds per hectare. The seeds of the two exotic species (*T. resupinatum* and *T. fragiferum*) were inoculated with type B rhizobia.

Dry-matter yields were determined 75, 90, 105, 120, 135 and 150 days after sowing. On each harvest date, a sample was taken from a 0.6 m^2 quadrat in the centre three rows. The plants were cut 2.5 cm above ground level. The herbage was oven dried at 65 ^{o}C for 72 hours for dry-matter estimation.

In 1983, the experiment was modified:

1. Seven additional clover species/ecotypes were included: *T. quartinianum* (ILCA 6278), *T. quartinianum* (ILCA 6777, ecotype 2), *T. steudneri* (ILCA 6253), *T. decorum* (ILCA 6303), *T. polystachyum* (ILCA 6298), *T. baccarinii* (ILCA 6294) and an introduced cultivar, *T. subterraneum* cv. Northern (ILCA 7023).

2. The trial was planted on two dates: (a) 15 March, during the short rains, and (b) 15 June, during the long rains, to investigate the effect of early planting on productivity of the clovers.

3. Dry-matter yields were determined 130 and 165 days after sowing, and at the end of the growing season.

The trial was laid out in a split-split-plot design with four replicates, with species as the main-plot treatments, the two planting dates as subplots and harvesting dates as sub-subplots. Plot size was 2 m x 3 m, comprising five rows 40 cm apart. Triple superphosphate was banded below the seed at a rate of 10 kg P/ha. The seed rates of the different species were adjusted to give the same number of plants per unit area as 8 kg of *T. tembense* seed/ha.

Seed treatment, planting, harvesting and determination of dry-matter yields were carried out as in the 1982 experiment.

Experiment 3

Concurrent with experiment 2 in 1982 a study was made of the effect of P applied at different rates on the dry-matter yields of *T. rueppellianum, T. tembense and T. fragiferum*.

The trial was planted adjacent to experiment 2 on the same day. The trial was laid out in a randomised complete block design with four replicates. Clover species and P rates (0, 5, 10, 20 and 35 kg P/ha, banded below the seed) were combined factorially. Plot management regimes were similar to those of experiment 2 of 1982.

In 1983 the trial was expanded to include nine species of clover: *T. quartinianum, T. tembense, T. decorum, T. steudneri, T. schimperi* (ILCA 6290), *T. rueppellianum, T. resupinatum, T. subterraneum* and *T. alexandrinum* (ILCA 6810).

The trial was planted on 21 June 1983 in a split-split-plot design, with species as main plots, fertilizer treatments as subplots and harvesting dates as sub-subplots. The subplots were 2 m x 4 m, within which samples were taken from 0.6 m^2 quadrats 75, 90, 105, 120 and 135 days after sowing. Seed rates and treatments and dry-matter yield determination were as previously described. Seed yield was also determined in the 0, 10 and 35 kg P/ha treatments. Samples for seed yield determinations were taken from two 90-cm segments in each guard row in each plot.

Experiment 4

Leaf tissues of plants in experiment 2 were sampled just prior to flowering, according to recommended procedures (Wolf, 1983; Martin and Matocha, 1968). The samples were analysed for P and N contents. Duplicate samples from dried whole plants were also analysed for percentage dry matter content, ash, calcium, neutral detergent fibre (NDF%), acid detergent fibre (ADF%), and lignin, whole-plant P and crude protein (CP) contents according to recommended procedures (Cottenie, 1980).

RESULTS AND DISCUSSION

Experiment 1

The accessions showed variations in flowering dates and highly significant differences ($P<0.01$) in branching, height, stem length and stem thickness.

Intraclass correlations of some morphological traits (leaf mark, plant height, leaf width, number of trifoliate leaves) for individual plants (I_{iws}) were substantially higher than those for accessions (I_s) (Table 1), which indicates that there may be genetic heterogeneity within accessions.

When soil characteristics (P and organic-matter contents and pH) of samples from the germplasm collection sites were subjected to discriminant statistical analysis (data not shown) they were shown to be unique to the axes from which they were collected. However, a similar analysis of the accessions gave imperfect allocation of accessions to the axes from which they were collected. For example, six

Table 1. Variance components for the morphological traits and their intraclass correlations as a measure of variability among *T. tembense* accessions (experiment No. 1).

Trait	Q^2_p	Q^2_{iwp}	I_p	I_{iwp}
Leaf mark	188.60	431.62	0.30	0.69
Plant height	2.44	13.91	0.15	0.86
Stem length	8.15	7.95	0.46	0.45
Petiole length	1.78	1.40	0.41	0.32
Branching	2.59	4.13	0.38	0.60
Leaf width	0.03	0.04	0.34	0.42
Stem thickness	0.05	0.19	0.18	0.71
Leaf length	0.07	0.13	0.08	0.85
Leaf width	0.01	0.19	0.05	0.94
No. of trifoliate leaves	0.00	0.34	0.05	0.80

Note: Q^2_p = Population variance (different accessions);
$Q2_{iwp}$ = Individual plants within populations;
I_p = Population intraclass correlation;
I_{iwp} = Individuals intraclass correlation.

accessions (ILCA 8285, 8106, 8258, 8142, 8198 and 8612) that were collected east of the Rift Valley were incorrectly classified into the collection areas lying to the west of the Rift Valley (Table 2). Thus, under the conditions of the trial it was not possible to show ecotypic variation in *T. tembense*.

Experiment 2

There were significant (P<0.01) species by harvesting date interactions on the dry-matter yields (Table 3). The dry-matter yields of the two native clovers, *T. tembense* and *T. rueppellianum*, peaked at 120 days after sowing and then

Table 2. Accessions misallocated to other collection axes due to overlapping morphological classification criteria as determined by discriminant statistical analysis and as an index of the absence of uniqueness of a particular population to its site of origin (Experiment 1).

Accession (ILCA No.)	From region	Misallocated into region	Posterior probability for misclassification
8285	45	67	0.578
8106	45	67	0.615
8612	45	81	0.921
8198	45	12	0.538
8142	45	12	0.394
8189	45	67	0.633
8258	45	81	0.458
8000	56	12	0.251
8764	56	67	0.365
8758	56	45	0.411
8001	12	81	0.521
8541	81	56	0.307

Note: Prior probability = 0.200 is less than the posterior probability values indicative of the 'strength' of misclassification (e.g. 0.578 is 57.8% misclassification) among accessions.

declined, possibly due to leaf loss. In contrast, the introduced species, *T. fragiferum* and *T. resupinatum*, continued to grow up to the final harvest 150 days after sowing.

It is possible that the early cessation of growth in the native clovers is an adaptive feature, which could be related to soil moisture availability or to photoperiodicity. This was investigated in 1983 using two planting dates.

Results from the 1983 trial show that planting the clovers in March (during the short rains) extended the length of the growing season of the native annual species by 15 to 87 days and increased the dry-matter yields by 75 to 640%

Table 3. Mean dry matter yields during the long rains at Shola under natural fertility (Experiment 2), 1982.

Species	Days after sowing					
	75	90	105	120	135	150
Controls	----------------kg/ha					----------------------
T. fragiferum	35	69	116	253	232	395
T. resupinatum	168	299	684	1331	1504	2053
Native						
T. tembense	274	237	1276	1626	1035	713
T. rueppellianum	135	353	769	1619	814	873

(Table 4). The highest dry-matter yields in the trial were produced by the early plantings of *T. quartinianum, T. tembense* and *T. rueppellianum.* The species by planting date by harvesting date interactions (second order) were highly significant ($P<0.01$). This was due possibly to large differences in yields among species in relation to their degree of adaptation (native vs introduced) and to seasonal environmental effects, e.g. the early-planted crops experienced less waterlogging of the soils in the early stages of growth (300 vs 800 mm rainfall), higher temperatures (23^{o} vs 15^{o} C mean maximum) and more sunshine (8 vs 3 hours of sunshine per day) than the late-planted plots.

Experiment 3

In the 1982 P application studies, both the species by fertilizer rate and the species by date of harvest interactions were highly significant ($P<0.01$). The introduced clover, *T. fragiferum*, had a much smaller dry-matter yield response to applied P than did the native clovers (Table 5).

Table 4. Dry-matter yields from several clover species grown at two sowing dates in 1983 at Shola, near Addis Ababa, Ethiopia.

Species or line	ILCA No.	Sowing date	Days to harvest 130	Days to harvest 165	End of growth	Days to end of growth
			-- DM yield (t/ha) --			
T. quartinianum	6301	15/3	3.3	5.0	6.3	233
		15/6	4.9	4.2	3.6	155
T. steudneri	6253	15/3	2.9	4.2	4.8	183
		15/6	2.6	2.5	2.1	136
T. decorum	6303	15/3	2.2	4.8	3.9	220
		15/6	2.9	2.4	1.8	136
T. rueppellianum	5791	15/5	2.7	4.5	5.1	230
		15/6	2.0	1.6	1.5	143
T. tembense	6278	15/3	1.8	3.3	5.8	217
		15/6	2.5	1.9	1.6	136
T. quartinianum (Ecotype 2)	6277	15/3	2.1	2.7	2.6	170
		15/6	1.1	1.1	1.2	155
T. polystachyum	6298	15/3	0.6	2.9	3.7	241
		15/6	0.3	0.1	0.5	160
T. resupinatum	7022	15/3	1.5	2.9	2.4	183
		15/6	0.2	0.1	0.2	190
T. subterraneum (cv. Northern)	7020	15/3	3.3	0.6	0.4	190
		15/6	0.8	0.5	0.7	160
T. baccarine	6294	15/3	1.0	1.6	0.9	198
		15/6	1.3	1.0	0.7	136
T. fragiferum	5280	15/3	0.25	0.15	0.04	356
		15/6	0.04	0.09	0.07	365+

Table 5. Effect of P application on dry-matter yields of three clovers at Shola, 1982 (Experiment 3).

Species	P rates (kg/ha) 0	2	4	10	Species overall means by W.D.
T. rueppellianum	1305	1491	2094	2904	a
T. tembense	1243	1776	2466	3228	a
T. fragiferum	135	232	260	246	b
P rate overall mean by W-D test	c	bc	ab	a	

W-D = Waller-Duncan T-test at K-ratio of 100:1 ($P<0.05$); Means of of the main effects with same letters were not significantly different.

The maximum yields of *T. tembense* and *T. rueppellianum* when fertilized with 10 kg P/ha were 4.8 and 4.0 t/ha, respectively, and occurred 120 days after sowing.

There were large dry-matter yield responses to applied P and higher rates of P produced larger yield responses.

The three main effects found in the 1983 P fertilizer trials are shown in Table 6. Regression models were developed for the effect of P on dry-matter yield, based on the 120-day yield data (Table 7).

Optimum rates of P application were found to be in the range of 25 to 30 kg P/ha for the native clovers. At higher rates of P application the increases in dry-matter yield were smaller. In 1984, when elemental P was $1.50/kg and hay was $0.44/kg, these rates were calculated to be the most economical.

The elasticity of response (Dillon, 1968), which indicates the rate of organic-matter synthesis (as an average percentage change of the slope of the response curve per unit

Table 6. Mean dry matter yields of several clovers sown at Shola in 1983.

Effects	DM yield (kg/ha)	Waller-Duncan[1]
Species		
T. quartinianum	2988	a
T. tembense	2124	b
T. decorum	2102	b
T. steudneri	1727	bc
T. schimperi	1418	cd
T. rueppellianum	1313	d
T. resupinatum	367	e
T. subterraneum	350	e
T. alexandrinum	169	e
Phosphorus kg/ha		
0	369	a
5	971	b
10	1519	c
20	1918	d
35	2199	e
Harvest times[2]		
75	496	a
90	943	b
105	1660	b
120	1934	c
135	1944	c

[1] Means with the same letters do significantly differ at $MSD_{0.05}$ of 408, 230 and 194 kg DM/ha for species, phosphorus rates and harvest times, respectively.

[2] Sixth harvest at 150 days omitted due to missing data but DM yields had considerably declined to about 50% of the maximum attained at 120 days.

Table 7. Dry-matter yield response functions due to P rates for various clovers tested at Shola in 1983.

Species	Equation for determining amount of yield	R^2
Linear effects	$(Y = a + bx)$	
T. subterraneum	$294.6 + 72.5x$	0.2408*
T. alexandrinum	$69.0 + 48.4x$	0.3539*
T. tembense	$1363.0 + 613.8x$	0.5800*
Quadratic effects	$(Y = a + bx + cx^2)$	
T. rueppellianum	$201.5 + 947.7x - 79.9x^2$	0.7853*
T. steudneri	$755.2 + 1186.6x - 98.3x^2$	0.7321*
T. decorum	$765.3 + 1285.7x - 106.9x^2$	0.7153
T. schimperi	$831.2 + 792.5x - 75.7x^2$	0.6464**
T. quartinianum	$904.1 + 2034.3x - 194.1x^2$	0.7194**

Y = DM yield, x = amount of fertilizer/ha coded as 0,2,4,6 and 7 representing 0,5,10,20 and 35 kg/ha rates in the equation above, respectively, i.e. the coded rates are to be inserted into the above equations in solving for Y. Any other coded rates desired to be inserted like 8,9,10, etc, should be interpreted in multiples of 5 as 40, 45, and 50, kg/ha, respectively.

b = linear regression coefficient

c = quadratic coefficient

*,** = Significant at 0.05 and 0.01 levels, respectively.

of P), was calculated from the quadratic regressions. The elasticity of response value indicated that at 5 and 10 kg P/ha the resultant rate of organic-matter synthesis in native clovers was 60 to 70%. At the optimum fertilizer rates (25 kg P/ha for most of the native species) the ER was only 10%.

These results, and those of the previous trial indicate the ability of the native clovers to respond to P over a wide range of rates of application.

Seed yield was also substantially increased by P application (Table 8). The species differed in their response to P, as indicated by the highly significant (P<0.01) species by fertilizer interaction.

Table 8. Effect of P fertilizer on seed yield for some clovers at Shola in 1983 (Experiment 5).

Species	Phosphate rates (kg/ha)		
	0	10	35
	Seed yield -----kg/ha-----		
T. tembense	212	541	1057
T. schimperi	533	817	945
T. quartinianum	478	659	748
T. decorum	305	222	728
T. rueppellianum	117	354	322
T. alexandrinum[1]	12	29	116

[1]Exotic clover for comparison. There were significant differences at P<0.01 for among fertilizer rates and among species differences.

Experiment 4

The native clovers had significantly (P<0.05) lower P concentrations in the leaf tissue than *T. fragiferum* (Table 9), which may indicate that they utilise P more efficiently than the introduced species. However, this could also have been due to mobilisation of P from the leaf tissues, but it is unlikely that this would have occurred before flowering.

Table 9. Effect of fertilizer and species on concentrations of N and P in leaf tissue.

Main effects	N%	P%
P rate		
0	4.1a[1]	0.213a
2	3.9a	0.233b
4	4.0a	0.253b
10	4.2a	0.253b
Significance level	n.s.	0.01
Species		
T. tembense	5.0a	0.211a
T. rueppellianum	4.8a	0.232b
T. fragiferum	2.3b	0.261c
Significance level	<0.01	<0.01
Overall S.E.	0.4	0.02

[1] Means followed by the same letter are not significantly different (Waller-Duncan, $P<0.05$).

S.E. = standard error of the mean.

Phosphorus application had little effect on crude protein content (Table 10) or lignin content (Table 11). However, there were significant ($P<0.05$) species by age of stand interactions due to the increase in lignin content and decrease in crude protein content as the native clovers matured.

Phosphorus application had no apparent effect on the *in vitro* digestibility of *T. rueppellianum* and *T. tembense* (Table 12).

Table 10. Crude protein content of whole plants as affected by P fertilization and clipping times.

Species	P rate (kg/ha)	Age of stand at clipping (days) 120	135	150	Mean
		------------ CP %		-------------	
T. fragiferum	0	21.4	19.2	13.4	18.0
	2	21.8	18.2	13.9	18.0
	4	17.0	15.6	10.6	14.4
	10	13.8	14.6	13.5	14.0
	Mean	18.5	16.9	12.8	16.7
	S.E±	1.9	1.1	0.8	1.1
T. rueppellianum	0	18.1	13.4	8.7	13.4
	2	17.8	14.4	9.0	13.7
	4	15.6	11.5	8.1	11.7
	10	16.6	10.4	6.7	11.2
	Mean	17.0	12.4	8.1	12.5
	S.E.±	0.6	0.9	0.5	0.6
T. tembense	0	17.3	10.6	10.3	12.7
	2	14.4	9.6	8.6	10.9
	4	15.8	11.3	10.3	12.5
	10	15.4	10.1	9.4	11.6
	Mean	15.7	10.4	9.6	11.9
	S.E.±	0.6	0.4	0.4	
P overall mean	0				14.7
	2				14.2
	4				12.9
	10				12.3
Overall mean		17.1	13.2	10.2	13.5
S.E.±		0.8	1.9	1.4	

Table 11. Lignin content of whole plants as affected by P fertilization and clipping times.

Species	P rate (kg/ha)	Age of stand at clipping (days) 120	135	150	Mean	S.E.+
		------- % lignin -------				
T. fragiferum	0	4.2	4.2	4.0	4.1	0.1
	2	4.5	3.8	4.8	4.3	0.3
	4	4.1	3.8	4.0	4.0	0.1
	10	3.9	4.5	4.0	4.1	0.2
	Mean	4.2	4.1	4.2	4.2	0.0
	S.E.±	0.1	0.2	0.2	0.2	
T. rueppellianum	0	5.6	7.3	9.2	7.4	1.0
	2	6.8	8.5	9.2	8.2	0.7
	4	6.2	7.9	9.2	7.8	0.9
	10	5.8	7.9	9.9	7.9	1.2
	Mean	6.1	7.9	9.4	7.8	1.0
	S.E.±	0.3	0.2	0.2	0.2	
T. tembense	0	6.0	8.4	8.6	7.7	0.8
	2	6.5	6.7	8.8	7.3	0.7
	4	5.7	8.3	8.4	7.5	0.9
	10	5.7	7.8	9.9	7.8	1.2
	Mean	6.0	7.8	8.9	7.6	0.8
	S.E.±	0.2	0.4	0.3	0.1	
Overall mean		5.4	6.6	7.5		
S.E.±		0.6	1.3	1.6		

Table 12. Predicted *in vitro* dry matter digestibility (DMD%) at full bloom as affected by P fertilization.

	P kg/ha	Plant fraction Leaves	Heads	Stems
		------------ DMD[1] (%) ------------		
T. resupinatum	0	78.5	N/A	77.6
T. rueppellianum	0	78.4	68.6	65.8
T. tembense	0	75.9	69.0	75.2
T. rueppellianum	4	76.6	54.5	66.7
	10	86.6	69.0	72.2
T. tembense	4	74.7	69.0	71.3
	10	76.1	70.5	77.3
Mean and S.E.		77.3±0.8	67.1±2.1	72.3±1.8
Range		74.1-80.6	54.5-70.5	65.8-77.6

[1] DMD % = 0.74 (DMS %) + 15.72 (L.J. Lambourne, personal communication) where DMS % = Dry matter solubility (pepsin/cellulase).

N/A There were no seed heads on this plant.

SUMMARY AND CONCLUSIONS

A study of 34 *T. tembense* germplasm accessions from the Ethiopian highlands indicated that there is a large amount of variation within the species, which would aid plant breeding programmes.

Native clovers showed large increases in dry-matter production at low levels of P application (less than 10 kg P/ha). Higher rates of P application showed that the native clovers could respond to a wide range of P rates (5 to 30 kg

P/ha). The leaf tissues of the native clovers contained less P than an introduced clover (*T. fragiferum*), indicating the greater efficiency of use of P of the local species. Seed yields were also substantially increased by applying P fertilizer, a factor of potential importance in commercial seed production.

Phosphorus fertilization had little effect on the N, crude protein and lignin contents of the leaf tissues or, as a consequence, on digestibility characteristics.

Early planting, in the short rainy season, resulted in longer growing seasons and higher dry-matter yields than later planting in the long rainy season. The high yields obtained from early planting may justify the risk of the uncertainty of sustained moisture availability during the short rains.

The relatively high yields of the native clovers observed in this study suggest that they are a potentially useful source of forage under proper management within the present farming systems in the Ethiopian highlands.

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THE PERFORMANCE OF LEUCAENA LEUCOCEPHALA ON SALT-AFFECTED SOILS

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ABSTRACT

The performance of leucaena (*Leucaena leucocephala* (Hawaii No. K8, cv. Brewbaker)) was investigated in pot culture experiments, using five arid-zone soils ranging in salinity from 0.75 to 16 ECe (mmhos/cm at 25 ^{o}C), and sodicity (ESP) from 6.8 to 46. The soil samples were either treated with or not treated with gypsum. Inoculated (Tal No. 1145 strain) and uninoculated replicates were arranged in a randomised complete block design and placed under full sunlight in the greenhouse. Moisture was maintained at field capacity throughout the growth period. The parameters studied included nodulation potential, foliage appearance, fresh and dry weights of tops, shoot and root lengths, N levels in shoot and root, and Ca, Mg, Na, K and Cl contents of plants. The data show that leucaena can grow successfully on these soils.

INTRODUCTION

Vast areas of the arid and semi-arid regions of Sudan consist of salt-affected soils that are poorly productive. The Soil Survey Administration of the Ministry of Agriculture and Natural Resources has surveyed about 400,000 hectares of such marginal lands in the Khartoum, Gezira, White Nile, Northern and Nile Provinces. However, very little research is being done on the reclamation and use of these soils.

The National Academy of Sciences (NAS, 1977; 1979) has recommended research on some legume species (e.g. *Leucaena leucocephala*) for use as forages and green-manure crops in the fragile ecosystems of the tropics, where vast areas remain barren because of their unsuitability for conventional crops due to poor soil conditions and lack of water. Moreover, Brewbaker et al (1981) emphasised the need for site adaptability studies on *Leucaena leucocephala* and other tree-legumes in tropical regions.

In recent years species of the genus *Leucaena* (subfamily Mimosoideae) have received considerable attention in the tropics and subtropics as an economically important plant group. Leucaena has desirable qualities such as high growth rate, drought resistance and tolerance to a wide range of soil and climatic conditions (Thoma, 1983; NAS, 1979; Brewbaker, 1978; Brewbaker et al, 1972).

According to our information there are no reports on site adaptability of leucaena in salt-affected soils. As a result, this study was started to examine the possibility of using such marginal soils as forage reserves, since there is an urgent need for good-quality fodder crops in Sudan. The objective of the work was to examine the performance of inoculated and uninoculated *Leucaena leucocephala* (Hawaii No. K 8 cv Brewbaker) grown in gypsum-amended and unamended salt-affected soils.

MATERIALS AND METHODS

The five soil samples used in this study were selected to include some of the major salt-affected soil groups south of Khartoum (within the immediate vicinity of Soba Agricultural Research Sub-station). The properties of the soils are summarised in Table 1. Organic carbon content was determined by the method of Walkley-Black (1934). Other characteristics were determined according to the methods of USDA (1954).

Table 1. Properties of the soils used.

Soil name	Soil order	SP (%)	pH	ECe mmhos/cm at 25o C	$CaCO_3$ (%)	CEC meq/100 g soil	Particle size distribution (%) Sand	Silt	Clay	OC (%)	Total N (%)	Cl^- meq/l	SO_4^{--} meq/l	ESP	SAR	Salinity and/or sodicity class
Soba(1) (S_1)	Aridisol	48	8.6	1.9	8.7	41	42	10	48	0.11	0.03	5	10.5	13.7	10.0	Non-saline - non-sodic
Soba(2) (S_2)	"	67	8.4	7.3	8.9	47	36	8	56	0.09	0.02	5	51.5	32.0	22.0	Saline-sodic
Soba(3) (S_3)	"	43	9.1	1.7	10.9	38	44	12	44	0.06	0.01	10	5.2	26	19.0	Non-saline sodic
Soba(4) (S_4)	"	52	8.0	16.0	9.6	42	36	12	52	0.06	0.02	27.5	127.2	46	36.0	Saline-sodic
Shambat (first Terrace) (S_5)	Entisol	54	8.2	0.75	6.3	37	34	24	42	0.11	0.04	2.5	4.3	6.8	3.0	Non-saline - non-sodic

Composite bulk samples of each soil were brought to the laboratory. They were then ground, sieved through a 2 mm mesh, mixed with gypsum at the rate of 12.5 t/ha and potted in medium-sized plastic buckets, each with 6 drainage holes.

The treatments used were:

g_0 = Unammended soil
g_1 = Soil amended with gypsum
I_0 = Uninoculated soil
I_1 = Soil inoculated with rhizobium strain Tal. No. 1145.

Treatment combinations were:

$g_0 I_0$ = unamended and uninoculated
$g_0 I_1$ = unamended and inoculated
$g_1 I_0$ = amended and uninoculated
$g_1 I_1$ = amended and inoculated.

Soil and treatments were combined in a completely randomised block design with 4 replicates.

The seed of *Leucaena leucocephala* (Hawaii No. K 8 cv Brewbaker) and the rhizobium strain (Tal No. 1145, an elite endophyte for *Leucaena leucocephala*) were supplied by Dr. Paul Singleton, Agronomist, NifTAL Project, University of Hawaii, Paia, Hawaii, USA.

The seeds of many tropical legumes germinate slowly and irregularly unless the testa is removed or made permeable. As such, the leucaena seeds used in this study were soaked in concentrated sulphuric acid for 15 minutes to break down the testa and to sterilise the surface of the seeds. The seeds were then washed with water until all traces of acid were removed.

The sterile seeds were planted in the plastic buckets, which contained 3.5 kg of soil (oven-dry basis) maintained at field capacity. Inoculum was applied to each hole by adding 1 ml of a turbid suspension of the test culture containing 10^9 cells/ml. Sterile dry gravel was spread over the surface of the soil to reduce the possibility of contamination through the top of the system. Macronutrients, mainly N (as a starter dose) and P, were added at sowing: 45 kg N/ha as urea and 250 kg P/ha as KH_2PO_4. A starter dose of N was considered to be necessary because the soils used are inherently deficient in nitrogen. A liquid micronutrient concentrate (Monterry Chemical Company, USA) was added at 0.5 ml per kg soil, which provided 7.5 mg Fe; 2.5 mg Zn; 2.3 mg Mn; 1.75 mg B; 0.75 mg Cu; 0.2 mg Mo; and 0.15 mg Co per kg of soil. The buckets were then placed in an unshaded space in the greenhouse during the winter. Weather data for the period of growth are given in Table 2. Moisture was maintained at field capacity by weighing and irrigating according to a consistent schedule.

The plants were cut at soil level 50 days after sowing, and the fresh weight and height of tops were determined. The plants were then dried at 70 ^{o}C, weighed, ground and composite

Table 2. Weather data for the peroid of growth (12 December - 31 January 1985).

Attribute	Range
Daily minimum temperature (^{o}C)	10.3 - 21.5
Daily maximum temperature (^{o}C)	25.6 - 37.5
Mean daily temperature (^{o}C)	16.8 - 33.2
Daily sunshine (hours)	6.3 - 10.9 (average 9.9)
Solar radiation (MJ/m^2 per day)	15.4 - 22.2 (average 18.7)
Pan evaporation (mm)	5.5 - 12.5 (average 9.3)
Wind velocity (miles/hour)	2.1 - 7.9 (average 5.0)
Rainfall (mm)	Nil

subsamples of each treatment were used for determination of total N, Ca, Mg, Na, K and Cl (USDA, 1954; Lavkulich, 1978; Chapman and Pratt, 1961). Immediately after the tops had been harvested, the roots were carefully removed from the soil for nodule observations and root total N determination.

RESULTS AND DISCUSSION

Seed germination

Germination counts were made on all the treatments under study. Rapid and uniform germination was evident one week after sowing, and 100% germination was observed in all treatments. The temperature (Table 2) was conducive to germination; alternating temperatures ranging between 20 and 32 ^{o}C have been reported to induce maximum germination in leucaena (Pathak and Patil, 1982).

Post-emergence growth was quite vigorous in all treatments. The leaves were medium to dark green and the plants appeared to be healthy, which indicates leucaena's potential for growth on such soils. Treatment differences did not show up clearly, however, until the plants were harvested.

Soil and treatment effects

Statistical analysis of the data showed that neither inoculation with rhizobium nor addition of gypsum to the soil had a significant effect on the characters studied, except for shoot length of leucaena, which was significantly reduced ($P<0.05$) by adding gypsum. However, there were significant ($P<0.05$) differences among the soils for all characters studied, except for chloride content of the leucaena (Table 3).

Munns and Franco (1981) mentioned salinity, alkalinity, acidity and sodicity of soils, among other factors, as potential constraints on legume production in tropical areas.

Table 3. Effect of soil type on plant characters and nutrient contents of *Leucaena leucocephala*.

	Soils				
Treatments	S_1	S_2	S_3	S_4	S_5
Fresh wt. of tops (g/plant)	1.43a	0.78b	0.69bc	0.46cd	0.46cd
Dry wt. of tops (g/plant)	0.46a	0.28b	0.24bc	0.16bcd	0.16bcd
Shoot length (cm)	14.5a	11.1b	9.4cd	7.3e	9.2cd
Root length (cm)	13.0bc	15.5a	12.8bcde	13.4b	12.6bcde
N % in shoots	3.4cd	3.5cd	3.7bc	4.4a	3.9b
N % in roots	2.6bcd	2.4bcd	2.7b	3.1a	2.7bc
Ca %	1.1a	0.9a	0.5b	0.4bc	0.4bc
Mg %	0.35a	0.30ab	0.30abc	0.20bcd	0.20bcd
Na %	0.06b	0.07b	0.12a	0.11a	0.02c
K %	2.5a	1.6b	1.2bc	1.0cd	1.0cd
Cl %	0.8	0.6	0.8	0.6	0.7

Within rows, numbers followed by the same letter are not significantly different at $P<0.05$.

The soils used in this study comprise soil orders similar to those mentioned by Munns and Franco (1981), viz Aridisols, Vertisols and Entisols. Moreover, the same authors found that the most likely nutrient problems in such soils are deficiencies of P, Zn, K, Mo and S. Some of these deficiencies are unlikely in aridic soils because they are alkaline. However, P fixation via adsorption has been documented by El Mahi and Mustafa (1980).

Leucaena performs poorly in acidic soils that are highly saturated with Al and low in P and Ca (Chee and Devendra, 1982), constraints which are not experienced in the soils under study. On the other hand, Jones (1979), working on *Leucaena leucocephala* as a feed for ruminants in the tropics, indicated that the sodium content of the plant is consistently low. However, the mineral composition of well grown leucaena is usually adequate for productive livestock (Table 3).

Nodulation potential

Nodulation was very sparse (< 10 nodules per plant) in the inoculated treatments and plants did not nodulate in the uninoculated treatments. However, some nodules may have been lost due to the fragility of their attachment to the roots. All the nodules found were active (pink to brown). The authors believe that the poor nodulation of leucaena in this study may be attributable to:

a. The soil salinity or sodicity, or both, which might have inhibited the functioning of the symbiosis (Singleton and Bohlool, 1983). Unsuccessful inoculation with specific endophytes due to soil chemical factors was reported by Dommergues (1981). Adding gypsum to the soil at the rate recommended in Sudan (12.5 t/hectare) did not, apparently, increase nodulation.

b. The fragile and narrow attachment of the nodule to the root (Halliday and Somasegaran, 1982).

c. Leucaena not being adapted to the area from which the soils were obtained. Halliday and Somasegaran (1982) reported that leucaena introduced to new areas is unlikely to encounter its specific rhizobial partner. This is substantiated by the coevolution concepts of rhizobial strains and their hosts and by documented cases of leucaena failing to nodulate in habitats that are remote from its natural distribution. For example, *Leucaena retusa*, a native of Texas, has not nodulated in Hawaian soils. However, there are reports (Bohlool and Schmidt 1973; Vidor et al, 1981) of introduced strains both easily colonising areas and failing to do so. Nevertheless, as judged from the vigorous growth and healthy appearance of the plants in this study, leucaena is able to colonise these soils without inoculation. Effective nodulation is, however, important to reduce the period during which the seedling behaves as a non-legume, especially in soils that are deficient in N, e.g. those used in this investigation. Nodulation alone is not sufficient evidence of the productivity of leucaena (Halliday and Somasegaran, 1981). Work is currently underway in our laboratory to isolate salt-tolerant strains of leucaena and other legumes.

d. Suppression of efficient nodulation might also be attributed to the N added as a starter dose. However, the authors believe that this is unlikely, since the soils used are inherently poor in nitrogen. An initial application of N is necessary for establishing plants in these marginal soils, because the plants may take up to 50 days to nodulate (Bushby, 1982). According to the author, even with inoculant levels at 200 times the normal rate the time to nodulate was slightly reduced. However, the poor nodulation on soils S_1 and S_5 (Table 1), which were non-saline, non-sodic and thus without any obvious deterents to plant infection, may support the theory that nodulation was suppressed by the N fertilizer.

Environmental factors

Temperature, solar radiation and rainfall affect the rate of growth of leucaena, and hence forage yield (Hegde, 1982). Different ranges of temperature have been reported to be conducive to the growth and development of leucaena at different altitudes and latitudes, e.g. $0^{o}C$ in winter to $41^{o}C$ in summer (Hegde, 1982); $20^{o}C$ to $32^{o}C$ (Pathak and Patil, 1982) and $25^{o}C$ to $30^{o}C$ (Houming, 1982). These temperature ranges are similar to the temperature range reported in this work (Table 2). Moreover, Dijkman (1950) stated that optimum rate of growth occurs under direct sunlight. Pathak and Patil (1982) found that the above-ground growth of leucaena and nodulation initiation were best at 45% light intensity and 32.7 ^{o}C, with fewer, larger nodules than at 100% light intensity and 35.4 ^{o}C. In this work we did not measure the light intensity but temperature conditions were similar. Furthermore, few reports in the literature separate the effect of solar radiation from that of temperature.

In conclusion we think that the marginal soils studied can support leucaena growth. However, quick economic returns cannot be achieved without sensible management and use of cultivars that are better adapted to the chemical and the physical constraints inherent in these soils.

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THE PERFORMANCE OF STYLOSANTHES SPECIES IN DIFFERENT PRODUCTION SYSTEMS IN NIGERIA

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ABSTRACT

The different pasture production systems discussed in this paper are: (a) pure legume pastures, (b) mixed legume/grass pastures, (c) mixed legume/cereal crops, (d) legumes/rangeland, (e) legumes for seed production, and (f) legumes in short fallows. Observations are reported on the performance of the three outstanding *Stylosanthes* species in Nigeria, namely *S. guianensis* cvs Cook and Schofield, *S. hamata* cv. Verano and *S. humilis*, and factors that affect legume performance in these production systems are discussed. Research problems associated with stylosanthes production and areas for future research are enumerated.

INTRODUCTION

Among the complex interacting factors that affect livetock production, nutrition is one of the most important. For ruminants, forage is the most important source of feed. In Nigeria, natural pastures do not meet the nutritional needs of grazing ruminants. Most of the liveweight gained in the wet season is lost in the dry season, resulting in low net annual growth.

Pasture research in Nigeria has aimed at improving dry season nutrition using legumes, some of the most outstanding of which are in the genus *Stylosanthes*. Three species, namely *S. guianensis* cvs Cook and Schofield, *S. hamata* cv.

Verano and *S. humilis* have received most research attention. This paper summarises the performance of these legumes under different production systems in Nigeria, such as in pure legume pastures, mixed pastures, with crops, in rangeland and under seed production.

PERFORMANCE OF STYLOSANTHES UNDER DIFFERENT PRODUCTION SYSTEMS

Pure legume pastures

Establishment: *Stylosanthes* species can be established by drilling or broadcasting seed into recent fallow, burned, disced or well-prepared seed beds (Haggar, 1969; Haggar et al, 1971; Agishi, 1971; de Leeuw, 1975). Well-prepared seed beds have given the best results and are recommended, particularly for seed crops. The application of dieldrin immediately before seeding at a rate of 200 ml a.i. in a 1% solution increased the plant density of Townsville stylo and Verano stylo more than three-fold and two-fold, respectively, over the control (Roeleveld and de Leeuw, 1978). Applying phosphate increases early establishment of Cook, Townsville and Verano stylos (de Leeuw, 1975, Holm, 1979; Agishi, 1982). A basal N application is beneficial on N-deficient soils, but high levels of N application have been shown to reduce nodulation and N fixation (Fayemi et al, 1970).

Schofield stylo grown under irrigation between March and May developed faster than when sown under rain-fed conditions during August and October (Agishi, unpublished). It was also found that stylo grew faster than gamba (*Andropogon gayanus*) during the dry season but slower in the wet season. The generally accepted view that stylo grows more slowly during the early stages of its establishment than do grasses may not apply to the later part of the dry season in northern Nigeria, when mean maximum air temperature is 30 °C and solar radiation is at its highest.

Herbage dry-matter yield: Applying P and S fertilizers increases the dry-matter yield of *S. humilis* (Fayemi et al, 1970), and similar results have been reported for Cook, Townsville and Verano stylos (Agishi, 1971; 1982; Holm, 1979). At Shika, applying 20 and 40 kg P/ha to 2-year-old stands of *S. humilis* and Townsville stylo, respectively, gave the highest dry-matter yields (Agishi, 1971). Applying phosphate fertilizer favoured weed invasion, particularly at higher P levels, but the effect was less in the second-year crop (Table 1). Small applications of phosphate fertilizer have been found to increase the yield of weeds more than that of stylo that had been established on a recent fallow (de Leeuw, 1972).

Table 1. The effect of single superphosphate on dry-matter yields of Schofield and Townsville stylos.

		kg P/ha			
Variety	Year	0	20	40	60
Schofield	1970	1282[a]	2783	2697	2409
		(53.1)[b]	(51.3)	(35.0)	(28.3)
	1971	4842	7159	5340	5299
		(69.3)	(70.7)	(58.9)	(59.2)
Townsville	1970	1800	2489	2630	2534
		(92.6)	(60.6)	(58.7)	(52.0)
	1971	2914	5960	7238	6734
		(81.5)	(71.4)	(63.6)	(69.5)

a. Dry-matter yield of legume component.

b. Percentage of stylo in total yield.

Light defoliation, either by cutting or by grazing animals, increases the legume content of the pasture (Haggar, 1971) but reduces the total herbage dry-matter yield when compared with an undefoliated pasture.

Stylosanthes/grass mixtures

The proportion of legume in a legume/grass mixture depends on:

- The species of legume
- The grass species in the mixture
- The initial ratio of legume seed to grass seed
- The type of seed bed
- Time and method of seeding
- The type, quantity and timing of fertilizer application
- Defoliation practice
- Relative palatability of legume to grass and
- The age of the pasture.

The salient points of these factors are discussed below.

Species mixtures: In both the rain-forest and the derived savanna zones of Nigeria, Schofield stylo was found to be compatible with *Andropogon gayanus* and *Melinis minutiflora*, but incompatible with *Cynodon plectostachyus, Digitaria decumbens, Panicum maximum* and *Pennisetum purpureum* (Hedrick, 1961; Adegbola and Onayinka, 1966). In the Guinea savanna, Schofield stylo combined well with *Chloris gayana* and *Panicum maximum* (Blair Rains, 1963; Haggar, 1969; 1971), and Cook stylo with buffel grass (Holm, 1979). Verano stylo has been reported to be compatible with *A. gayanus, Cenchrus ciliaris, C. gayana, P. maximum* var *trichoglume, P. maximum* cv. Gatton and *Urochloa mosambicensis* (Shehu, 1980; Agishi, 1982). Townsville stylo combines poorly with *C. plectostachyus* and *Digitaria smutsii* (Anon., 1972).

At Shika, Onifade (1982) found that herbage dry matter yields of Cook stylo increased with increasing proportions of Cook stylo seed in stylo/Rhodes grass mixtures and that this effect persisted into the second year (Table 2). Total dry-matter yields were similar in all treatments, showing that increases in legume dry-matter yields resulted in proportional decreases in the grass component.

Table 2. Effect of Cook stylo/Rhodes grass seeding ratios on dry-matter yield.

		Legume % in seed mixture				
		30	40	50	60	70
1979	DM yield	4290	4210	4650	5010	5200
	% legume	18.9	20.9	25.8	27.9	31.5
1980	DM yield	8240	8440	8390	8280	8610
	% legume	18.1	21.0	23.6	25.7	36.6

Townsville stylo and Verano stylo performed poorly when sown into existing pastures of green panic and Gayndah buffel grass (de Leeuw et al, 1980). However, defoliation increased legume yield, particularly at higher defoliation frequencies (Table 3). Haggar (1971) reported that the proportion of stylo in an unfertilized stylo/Rhodes grass mixture was lower under 4 cuts than 2 cuts per year, but that the proportion of stylo diminished more under the 2 cut than the 4 cut treatment when N was applied (Table 4).

In the Northern Guinea savanna, Schofield, Townsville and Verano stylo can be planted at any time between June and July without having a significant effect on yield (Agishi, 1971; Roeleveld and de Leeuw, 1978). Erratic rainfall experienced during this period, however, reduces Townsville stylo production, but has little effect on Verano stylo yield (Roeleveld and de Leeuw, 1978).

In Shika, Onifade (1982) compared broadcasting Cook stylo and Rhodes grass in alternate rows and mixing the seeds before broadcasting. He found that seeding by broadcast gave the best legume dry-matter yield. Herbage dry-matter yields showed no significant differences between sowing treatments.

Table 3. Total dry matter yield of Townsville stylo and Verano stylo undersown in panic and buffel grass pastures.

Treatments	Green panic	Townsville	Verano	Buffel grass	Townsville	Verano
	Yield (t/ha)					
Cut in July and October	4.5	0.56	0.73	6.00	0.25	0.31
Cut in July, August and October	3.9	1.04	1.50	5.00	0.73	0.67
Cut in July, August September and October	3.6	1.41	1.44	5.2	0.90	1.23
Cut only in October	4.2	0.08	0.46	5.2	0.13	0.21

Table 4. Effect of N application on stylo and crude protein contents of stylo/Rhodes grass pasture under two and four cuts per year.

Nitrogen level (kg/ha)	Percentage stylo		Crude protein (%)	
	4 cuts	2 cuts	4 cuts	2 cuts
0	37.7	41.6	11.9	10.2
84	30.4	15.8	13.2	11.3
168	22.2	106.0	13.8	12.5
252	20.9	4.3	14.6	11.0

Fertilizer application: Applying N fertilizer on a legume/grass mixture at Shika reduced the legume component, the amount of reduction being related to N level, especially under light defoliation (Haggar, 1971). It is possible that applying N to frequently cut stylo increases the crude protein content of the stylo (Table 4). Applying nitrochalk (26% N) to a Cook stylo/Rhodes grass mixture at 0, 100 and 200 kg N/ha, gave legume dry-matter yields of 2.5, 2.10 and 1.76 t/ha respectively (Onifade, 1982). Superimposing cutting regime on N treatment increased the legume content only slightly.

Both P and S reduce grass dry-matter yields, particularly in the second year, but increase the yield of a stylo/rhodes grass mixture (Haggar, 1971). Haggar also found that S had a greater effect on stylo yield when applied with up to 67 kg P/ha. The application of micronutrients has been reported to be beneficial to Cook stylo and Verano stylo growth (Mohamed-Saleem, 1984) but detailed work is yet to be done in this field.

Defoliation management: Frequent defoliation has been reported to increase the proportion of Townsville and Verano stylos in mixtures with buffel grass and green panic (de Leeuw et al, 1980). The dry-matter yield of stylo in a stylo/rhodes grass mixture was higher under 4 cuts than under 2 cuts per year (Haggar, 1971). A similar finding was also reported by Onifade (1982) on Cook stylo/rhodes grass mixture. Both Verano stylo and Townsville stylo contributed more to the dry-matter yields of mixtures with buffel grass and green panic under defoliation than when non-defoliated (Shegu et al, 1980).

Observations in the Northern Guinea savanna have shown that both frequent and close defoliation of *S. humilis*/grass mixtures result in pronounced reduction in the proportion of the sown species and a dominance of such unpalatable weed species as *Sporobolus pyramidalis*, *Brachiaria stigmatisata* and *Sida* spp. Verano stylo, on the other hand, increases its proportion in a mixture with grass when grazed at high stocking rates. For example, the proportion of Verano in mixture with buffel grass, grazed at 1.1, 1.67 and 3.33 heifers/ha, was 10.2, 16.2 and 13.8%, respectively in the first year and increased to corresponding values of 28.3, 44.7 and 60.5% 4 years later (Agishi, 1982).

Stylo is reported to have low palatability to stock in the wet season (Blair Rains, 1963; de Leeuw and Brinckman, 1974), which explains the increase in the proportion of stylo and the decrease in that of grass under grazing (Anon., 1972). Observations at Shika, however, show that under high stocking rates, when selectivity is low, cattle readily graze stylo during the wet season. At high stocking pressure, the proportions of both sown grass and stylo decrease drastically due to increases in volunteer grasses and other weeds, but the decrease is greater in stylo. Verano stylo is readily eaten by cattle in the wet season, but is preferred by goats and sheep at a mature stage (Agishi, 1982).

The proportions of *S. humilis*, Townsville stylo and Verano in mixtures with grasses increase significantly with time up to a point (de Leeuw, 1972; Adamu, 1977; Shehu, 1981; Onifade, 1982; Agishi, 1982). This increase in legume content with time can be modified by management methods already described above and by leaf fall. After 3 years, stylos tend to disappear from the pasture.

Stylosanthes/crop mixtures

Early experiments at Shika on the establishment of Schofield stylo and Townsville stylo into maize and millet showed that these species could be sown under cover crops provided the canopy was removed 4-7 days after seeding the legumes. The earlier maturing millet with an open canopy was more suitable than maize, which has a thick canopy (de Leeuw, 1975). Legume plant counts in the first and second years of establishment are shown in Table 5. Plant populations for the early cut were comparable to populations observed when these legumes were sown in pure stands. The Table shows the detrimental effect of late cutting of maize (harvested for grain) on legume populations. The survival of Townsville stylo and *S. humilis* was three and seven times higher, respectively, when the maize was harvested early than when it was harvested for grain. With millet, the planting density and date of harvest of the millet had little effect on the legume regrowth.

In a current experiment at Shika on cereal/legume mixtures involving Cook stylo, maize and sorghum sown in alternate rows, stylo establishment was poor. However, by August of the second year, stylo cover had reached 50-75% and 75-90% in maize and sorghum plots respectively (Mzamane and Agishi unpublished).

A more detailed study of stylo/crop interactions is currently underway in an ILCA project in the subhumid zone of Nigeria (Mohamed-Saleem, 1984). Results obtained so far show that:

1. Sowing Cook stylo or Verano stylo at the same time as sorghum gave the highest legume herbage yield but drastically reduced sorghum grain yield. Under-sowing these legumes 3 and 6 weeks after the sorghum gave a good balance between sorghum grain yield and legume herbage yield and also increased the quality of harvested fodder (Mohamed-Saleem, 1984).

Table 5. The effect of plant population and cutting date of maize and millet on survival of undersown stylo and Townsville stylo.

			Cereal population (plants/ha)						
			48,000		71,000		143,000		
Cereal	Legume	Time of harvest	1st yr	2nd yr	1st yr	2nd yr	1st yr	2nd yr	Mean
Maize	S. humilis	Early	283	132	237	57	332	71	87
		Late	198	13	591	25	156	3	165
	Townsville	Early	229	66	254	97	167	163	109
		Late	280	41	192	14	161	39	31
Millet	S. humilis	Early	79	59	119	46	237	99	68
		Late	251	65	120	69	146	75	70
	Townsville	Early	219	156	195	198	75	338	231
		Late	82	161	220	237	134	138	179

2. Planting stylo and sorghum either on ridges or on flat seed beds had no significant effect on stylo yield but planting on ridges increased sorghum yield.

3. Spraying the existing stylo crop to introduce a crop reduced legume yield, particularly on ridged plots. At Shika, sowing sorghum into a 2-year-old Verano stylo pasture in rows 2 m apart did not affect the dry-matter yield of the stylo. Removing stylo plants within a 30 cm radius of each sorghum plant improved sorghum establishment. Applying N significantly increased sorghum herbage and grain yields (Agishi, 1978).

Stylosanthes in recent fallow

At Shika, introducing *S. humilis*, Cook stylo and Verano stylo into recent fallows has been found to be the cheapest way of establishing them. In this method, plots to be sown to the stylos are planted to millet or early maturing maize, which are harvested in late August or early September. Immediately after harvest, the land is harrowed and planted to stylo. Alternatively, *S. humilis* or Verano seeds can be planted directly into the fallow by broadcasting or drilling. The young seedlings make limited growth by the end of the rains but remain alive for the 5-6 months of the dry season.

The seedlings resume fast growth with the onset of the rains, competing strongly with associated weeds. The application of 8-16 kg P/ha enhances the dominance of the legume. The method has many advantages:

* The cost of a separate seed bed preparation is reduced or virtually eliminated.

* The phosphate applied to the cereal crop benefits the legume.

* It is easier to manage than cereal/legume mixtures.

* It is cheaper to establish than a pure legume pasture.

* On land that has been infested with noxious weeds or has erosion problem, this method can be used to make it productive again.

* It requires only 2-3 weeks of rain at the end of the growing season for the legumes to establish well.

The main disadvantage with this method is that the legume cannot be grazed in the year of establishment.

Stylosanthes in rangeland

Attempts to establish and grow stylos in the Nigerian rangelands have had mixed results. The successes reported in Australia with establishing Townsville stylo in rangeland have not been matched in trials in Nigeria. The poor performance of *Stylosanthes* has been attributed to removal of most of the seed by ants and by shading from the existing vegetation (de Leeuw, 1975).

Stylo has been successfully established in the southern Guinea savanna at Mokwa by sowing into cultivated strips in rangelands (Agishi, 1971). In the northern Guinea savanna, where strip cultivation was limited to only disc-harrowing, establishment and performance were poor and were only improved when oversowing was repeated in the following year (Haggar et al, 1971). It was also found that applying superphosphate increased stylo establishment but the effect did not persist. Earlier studies by Foster (1961) showed that stylo could be introduced into the range by feeding seed to the grazing cattle, but application of this technique is limited by the high cost of stylo seed.

Numerous efforts by a World Bank team to establish *S. humilis* and Verano stylo by broadcasting seed onto harrowed strips in degraded grazing reserves in the Sudan zone (Kukar-Jangarai) failed (Perrier, 1982). It was postulated that removal of seed by ants and the hard soil surface reduced germination. A controlled study carried out later on methods of stylo establishment in this reserve indicated that harrowed strips recrusted fast and so provided no improvement in water infiltration (Perrier, 1982).

De Leeuw's (1972) studies on this grazing reserve showed that *S. humilis* and Townsville stylo established and grew best on burned or cultivated sites, with phosphate application giving an additional benefit. Verano stylo has performed better in the Sudan zone than *S. humilis* (Perrier, 1982).

Stylosanthes planted in unimproved seed beds has performed best in Nigeria in Benue state. Townsville stylo was first introduced to Yander Agricultural Research Station in 1956 and today it covers many square kilometers of fallow land, roadsides and rangeland in the state. The centres of spread are the cattle routes. Townsville stylo associates well with *Imperata cylindrica*. Best growth is to be seen in areas receiving repeated defoliation such as cattle routes and sport fields.

Stylosanthes for seed production

S. humilis, Townsville stylo and Verano stylo grown for seed production in Nigeria are managed in one of the following ways:

a. The pasture is left unweeded throughout the year and seeds are harvested when ripe,
b. The pasture is weeded once or twice a year before seed harvesting,
c. The pasture is grazed between June and August, and then the paddock is closed to grazing to allow seeds to form and mature.

Method (a) is not suited to producing seed of any of the stylo species; about 8 weeks after establishment, the pasture is dominated by weeds. Method (b) is suitable for all three species, as competition for light and soil nutrients is almost totally eliminated. Plants grow vigorously and produce a lot of bulk and seed, particularly in the second and third years after establishment. Method (c) favours Verano stylo and Townsville stylo more than *S. humilis*, which tends to thin-out where grazing pressure is high. However, at high pressure, grazing should be stopped at least 6 weeks before the end of the wet season, in order to allow stylo to recover and set sufficient seed.

Stylos managed for seed production usually regrow from seed at the onset of the rains. In this way even the perennial stylos are managed as annuals. Each year, a new pasture is re-established from seeds, and so the productive life of the pasture seed crop is longer than grazed pastures of the same species. Observations have shown that grasses and other nitrophilous weeds become dominant after 4 to 5 years, even in seed crops, due mainly to the accumulation of N in the soil. In such a situation, hand weeding or grazing by cattle followed by phosphate application may help to increase the legume content of the pasture.

Stylosanthes in citrus orchards

In the humid and sub-humid areas of Nigeria, many citrus orchards have been established. Because of the normally wide spacings between plants, weed infestation is a problem. Weeding large tracts of land under citrus is not feasible, but weeds can be controlled by planting the areas between the trees with a stylo pasture. The areas between the trees are harrowed and seeds of stylosanthes broadcast onto it.

With the break in rainfall during December and January, the Verano stylo or Townsville stylo is cut with sickles and the fallen seed swept from the ground. The cleaned seed is sold, but the cut herbage is left on the farm to be grazed by livestock and to provide mulch for the trees. Difficulties have been experienced in cutting Cook stylo because of the relatively large, woody stems. Though goats and sheep would not touch any of the stylos during the wet season in the first 2 years of the pasture, they now readily consume large quantities. It was also observed that the soil under a 5-year-old orchard, when planted to Townsville stylo, became very friable and had many earthworm casts only 2 years after planting the stylo. A similar observation was made in the soil which had been under Cook stylo for 3 years. Harvesting the stylo and grazing by sheep and goats help to keep down the weeds in the orchard.

Problems and gaps in Stylosanthes research in Nigeria

Lazier (1984), writing on Stylosanthes in West Africa, listed the following problems with stylos:

a. Sensitivity to shading.
b. Low persistence beyond 3 years.
c. Termite attack, causing death of stands.
d. Fire outbreaks on mature stylosanthes pastures, causing huge losses.
e. Anthracnose, which can cause death of stands.
f. Difficulty in obtaining stylosanthes germplasm.

In addition to these problems, there is an acute shortage of trained manpower in pasture legume research.

Some of the gaps in stylosanthes research in Nigeria include:

a. Narrow germplasm base.
b. The nutrient requirements of stylosanthes on different soil types are not fully known.
c. Little is known on the effects of micronutrients on the performance of stylosanthes in Nigeria.
d. *Stylosanthes* spp. are being recommended for inclusion in

cereal crops, but the nature of competition in these mixtures is yet to be understood.

e. The performance of *Stylosanthes* spp. under irrigation has not been properly investigated.

f. Technology for weed control in stylosanthes pastures needs to be developed.

g. Cutting and grazing studies are very short term, and little is known of the long-term performance of *Stylosanthes* species.

To fully exploit the great potential of the genus *Stylosanthes* in improving livestock production in Nigeria, there is need to intensify research to cover to points outlined above.

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ESTABLISHMENT AND EARLY SURVIVAL OF NINE PASTURE LEGUMES OVERSOWN INTO NATURAL PASTURES IN NORTHERN TANZANIA

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ABSTRACT

In this study, which was conducted at Tengeru, Arusha, in northern Tanzania, over 61 weeks, nine pasture legumes were oversown into natural pastures. Four seedbed preparation methods were used, namely burning, hard grazing, cultivation and normal grazing (control) with or without phosphatic fertilizer.

Sixteen seedling and plant counts were made to determine germination, establishment and survival of the legumes. Of the nine legumes, *Desmodium intortum* (cv Greenleaf desmodium) and *Macroptilium atropurpureum* (cv Siratro) were significantly better than the other legumes in terms of germination, establishment, survival and percentage contribution to total dry matter. For most legumes, establishment was most successful following burning or hard grazing of the native pastures.

The implications of these findings are discussed with special reference to the possibilities of improving natural grasslands by introducing selected pasture legumes by oversowing.

INTRODUCTION

Located in East Africa, 1° south of the equator, Tanzania has a human population of about 20 million (17.5 million by the 1978 census) and a ruminant livestock population of 12.1 million cattle, 5.5 million goats and 3.6 million sheep (Ministry of Agriculture, 1979). Of its total area of 93.7 million hectares, 60% is natural grasslands which are available for grazing (Ministry of Livestock Development, 1983). These grasslands are mostly in ecoclimatic zones IV and V described by Pratt et al (1966). They are characterised by low, erratic rainfall, usually 760 mm or less total annual rainfall, and a high evapotranspiration potential of more than 1800 mm. Grasses, of which *Themeda* and *Hyparrhenia* species are dominant, grow rapidly and quickly reach flowering and seeding stages during the rainy season (French, 1957).

The natural grasslands are the sole source of feed for over 90% of the country's ruminant livestock and herbivorous game. However, the productivity and quality of the herbage from these natural grasslands are low (Calo, 1976). Any attempt to increase the productivity of the country's ruminant livestock must, therefore, involve development and improvement of these natural grasslands.

The three main approaches to development and improvement of natural grasslands are (a) improvement of their management and utilisation, (b) introduction of suitable improved pasture species into the natural pastures, and (c) a combination of the first two approaches, whereby improved legume species are introduced into natural grasslands by oversowing and the resulting pastures subjected to improved management and utilisation (Kusekwa and Lugenja, 1983; Lwoga, 1978; 1979; 1983).

In Tanzania, the first approach is constrained by the inherent low productivity and low quality of herbage of the existing plant species in the natural grasslands (Calo, 1976; Mannetje, 1981). Replacing existing plant species with improved ones by cultivation and seeding is, on the other hand, unlikely due to the high costs involved. Thus, the third approach, oversowing, seems to be the most realistic. Oversowing involves seeding directly, either by sod seeding or surface broadcasting, into a live, chemically killed or partly disturbed natural grassland (Cook, 1980). In East Africa, Keya and Eijnatten (1975) and Stobbs (1969) observed that oversowing was a possible method for improving natural grasslands. Keya and Kalangi (1973) in Kenya reported successful oversowing of the legume, *Desmodium uncinatum* into a *Hyparrhenia*-spp.-dominated natural grassland with superphosphate fertilizer applied at the rate of 500 kg/ha. This pointed to the need to correct mineral dificiencies for the successful establishment of pasture species with a high fertility requirement. Walker (1977) also pointed out the need for phosphatic fertilizers with legume-based pastures.

Work in Tanzania on oversowing of promising pasture legumes is scanty. Lane and Lwoga (1978) at Morogoro, Tanzania, observed that oversowing of pasture legumes needed further investigation.

This study was aimed at determining the best methods of oversowing pasture legumes into natural grasslands, with or without the application of phosphatic fertilizers. This paper reports results of an experiment in which nine legunes were oversown into natural grasslands at Tengeru, Arusha, in northern Tanzania.

MATERIALS AND METHODS

The experiment was conducted from April 1979 to June 1980 at the Livestock Training Institute, Tengeru, in Arusha, northern Tanzania, 3°24' S and 36°47' E at an altitude of 1260 metres above sea level. The climate is subhumid, with a mean annual rainfall of about 1100 mm and maximum temperature of 28.2°C during February and 12.3°C minimum temperature in July.

Table 1 shows the rainfall during the experimental period along with the 20-year mean monthly rainfall.

Table 1. Monthly rainfall for April 1979 to June 1980 and the 20-year mean monthly rainfall, Tengeru, Tanzania.

Month	Rainfall (mm)	Rain days	20-year mean Rainfall (mm)	20-year mean Rain days
April 1979	305.1	21	365	19
May 1979	241.0	21	145	18
June 1979	2.7	2	30	4
July 1979	1.4	2	15	6
August 1979	12.0	3	13	7
September 1979	25.8	6	12	5
October 1979	57.2	11	47	12
November 1979	Nil	Nil	93	13
December 1979	21.1	6	101	9
January 1980	28.8	4	59	4
February 1980	62.4	6	61	3
March 1980	49.2	6	143	8
Total for 12 months	806.7	88	1084	108
April 1980	259.2	15	365	19
May 1980	101.7	16	145	18
June 1980	1.4	2	30	4
Total for experimental period	1146.3	118	1624	149

The experimental site was under natural pasture and had for many years been subjected to light grazing, and had thus reverted to acacia bush. Desirable grasses, which comprised about 80% of the botanical composition of the pasture, included *Bothriochloa insculpta, Cynodon dactylon* and *Panicum* spp. Legumes present were *Rhynchosia* spp. and *Vigna* spp. Predominant weedy species were *Ageratum conyzoides* and *Bidens pilosa*.

Soils at Tengeru are dark brown, silty, clay-loam developed on colluvium, derived mainly from lavas (Anderson and Naveh, 1968); but the soils at the trial site were mainly vertisols with their usual characteristic of being waterlogged during the rainy season and cracking in the dry season.

The experimental treatments comprised factorial combinations of four seedbed preparation methods, three levels of P application and nine legume species. A randomised block design with split plots was used with two replicates. Seedbed preparation methods were the mainplot treatments and 27 combinations between P fertilizer levels and legume species were the subplot treatments.

Seed preparation treatments were as follows:-

Normal grazing (control): Dry dairy cows grazed off about 50% of the available dry matter, followed by hand trimming. This treatment simulated a normally grazed natural pasture.

Hard grazing: Dry dairy cows grazed off about 50% of available dry matter, followed by hand slashing of the pasture to remove about 75% of available total dry matter. This treatment simulated a closely or overgrazed natural pasture.

Burning: Paraquat was applied at 0.5 kg a.i./ha to desiccate the pasture, which was then burned. This simulated a burnt natural pasture, a common feature in these areas.

Cultivation: Heavy discing was done using a tractor-drawn disc plough to destroy the existing vegetation.

Legume species sown are shown in Table 2.

Table 2. Legume species used in the trial.

Species/cultivar	Germination (%) Minimum	Germination (%) Actual	Number of seeds/plot	Number of seeds/quadrat (1000 cm2)	Number of pure germinating seeds/quadrat
Macroptilium atropurpureum (cv Siratro)	70	70	450	4	4
Medicago sativa (cv Hunter River)	80	33.3	7920	66	27
Stylosanthes hamata (cv Verano stylo)	40	40	1320	11	11
Stylosanthes humilis (cv Townsville stylo)	40	12.9	6600	55	18
Desmodium intortum (cv Greenleaf desmodium)	70	70	3775	31	31
Desmodium uncinatum (cv Silverleaf desmodium)	70	70	1100	9	9
Leucaena leucocephala (cv Standard leucaena)	60	40	288	3	2
Neonotonia wightii (cv Cooper glycine)	60	6.3	9240	77	8
Clitoria ternatea (cv Clitoria)	60	60	408	4	4

Fertilizer was broadcast at sowing at 0 (P_0), 23.1 (P_1) and 46.2 kg P/ha (P_2).

Sowing : The legumes species were surface sown on 3 m x 4 m subplots after having been inoculated with the appropriate rhizobia. Sowing date was 12 April 1979.

Measurements: The number of seedlings or plants per subplot was estimated by taking seedling/plant counts in four randomly placed 1000 cm^2 quadrats (40 cm x 25 cm) in each subplot. Sixteen counts were made at weekly intervals to determine germination, establishment and survival of the oversown legume species. The last count was taken 140 days after sowing on 30 August 1979. Dry-matter production and botanical composition were also determined by separation of herbage samples from three 1000 cm^2 quadrats per subplot. These measurements were taken 55 weeks and 61 weeks after sowing on 2 May 1980 and 13 June 1980, respectively. Other observations made included scoring for vigour, leafiness, colour (greenness), uniformity (cover) and presence of pests and diseases.

RESULTS

In this paper, results for five seedling or plant counts are given: (1) 7 days after sowing, on 19 April 1979, corresponding to germination; (2) 28 days later, on 17 May 1979, corresponding to establishment; (3) 63 days after sowing, on 14 June 1979; (4) 98 days after sowing, on 19 July 1979; (5) final count taken 140 days after sowing, on 30 August 1979. Germination of lucerne and Greenleaf desmodium was first observed 5 days after sowing.

Table 3 shows that Siratro was consistently superior to the other legumes in terms of germination, establishment, growth and survival. It was followed by clitoria then the desmodiums. The means of counts 1-3 differed significantly from the means of counts 4 and 5 ($P < 0.05$), suggesting that some seedlings died after establishment.

Table 3. Ranking (R) of legume species by germination (Count 1), establishment (Count 2), growth and survival (Counts 3-5). The number of seedlings/plants are expressed as percentages of pure germinating seed sown, Tengeru, Tanzania, 1979/80.

Legume species	Count 1 %	Count 1 R	Count 2 %	Count 2 R	Count 3 %	Count 3 R	Count 4 %	Count 4 R	Count 5 %	Count 5 R	Means for legumes %	Means for legumes Rank
Macroptilium atropurpureum (cv Siratro)	80.2	1	97.9	1	100.0	1	100.0	1	97.9	1	95.2	1
Medicago sativa (cv Hunter river)	44.3	6	30.3	7	15.2	9	12.4	9	7.9	8	22.0	8
Stylosanthes hamata (cv Verano)	29.0	7	35.7	6	38.4	4	33.5	5	27.7	5	32.9	5
Stylosanthes humilis (cv Townsville)	28.6	8	23.9	8	21.8	8	17.8	8	15.8	7	21.6	9
Desmodium intortum (cv Greenleaf desmodium)	54.5	3	47.9	3	35.0	5	37.1	4	33.4	4	41.6	4
Desmodium uncinatum (cv Silverleaf desmodium)	52.7	5	42.8	5	55.4	3	54.5	3	34.9	3	48.1	3
Leucaena leucocephala (cv Standard leucaena)	54.2	4	47.9	4	31.3	6	21.4	7	6.9	9	32.3	6
Neonotonia wightii (cv Cooper glycine)	25.6	9	22.1	9	28.2	7	21.8	6	22.0	6	23.9	7
Clitoria ternatea (cv Clitoria)	60.4	2	80.2	2	92.7	2	90.6	2	73.9	2	79.6	2
Means for counts	47.7		47.8		46.5		43.2		35.6			
LSD (0.05)	10.3		8.5		9.5		9.2		6.5			
LSD (0.01)	13.6		11.2		12.4		12.1		8.6			

Table 4 shows that hard grazing and burning favoured germination, establishment, growth and survival of the legumes oversown on natural pasture, although the differences between the grazing and burning treatments was not significant. The establishment, growth and survival of the legumes was significantly poorer in the cultivated treatment than in the other three treatments.

Table 4. Effects of methods of seedbed preparation on germination, establishment, growth and survival of legumes oversown into a natural pasture, Tengeru, Tanzania, 1979/80.

Seedbed preparation methods	Counts					
	1	2	3	4	5	Mean
Burning	49.3	47.9	44.2	46.5	38.8	45.3
Hard grazing	52.5	54.7	51.9	48.7	39.5	49.5
Cultivation	43.5	39.3	37.8	33.6	27.8	36.4
Normal grazing	45.6	48.7	52.0	44.1	36.3	45.3
Means	47.7	47.8	46.5	43.2	35.6	
LSD (0.05)	NS	12.6	12.7	12.3	12.5	

NS not significant (P>0.05).

Phosphorus application had no significant effect on any of the plant counts. However, from the third plant count up to the final count, there were indications that higher levels of P favoured the establishment and survival of oversown legumes.

The total dry-matter yields from plots oversown with the various legumes did not differ significantly. Greenleaf desmodium and Siratro plots, however, gave the highest yields, of 3.6 and 3.5 t DM/ha, respectively. Seedbed preparation methods and P application did not have significant effects on the percentage contribution of legumes to total dry-matter yields.

Table 5 shows that the percentage legume contribution to total-dry matter yields at the first harvest was highest in Siratro plots followed by Greenleaf desmodium and lowest in lucerne and Townsville stylo plots.

Table 5. Ranking of legume species by percentage contribution to total dry-matter yields. Harvest 1 taken 55 weeks after sowing and harvest 2 after 6 weeks regrowth from harvest 1.

	Harvest 1		Harvest 2		Mean	
Legume	%	Rank	%	Rank	%	Rank
Siratro	38.0	1	26.0	1	32.0	1
Lucerne	0.8	7	0.4	8	0.6	8
Verano stylo	12.2	4	12.8	3	12.5	3
Townsville stylo	0.2	8	1.3	7	0.75	7
Greenleaf desmodium	27.8	2	7.9	5	17.85	2
Silverleaf desmodium	11.0	5	4.2	6	7.6	6
Leucaena	0.0	9	0.0	9	0.0	9
Cooper glycine	10.2	6	14.0	2	12.1	4
Clitoria	12.8	3	11.1	4	11.95	5
Mean	12.60		8.60			
LSD (0.05)	3.15		3.23			
LSD (0.01)	5.36		5.56			

At the second harvest, which was taken 6 weeks later, performance, in descending order, was Siratro, Cooper glycine, Verano stylo, Clitoria, Greenleaf desmodium, Silverleaf desmodium, Townsville stylo, lucerne and then leucaena. This indicated that legume regrowth over the 6 weeks varied with species.

DISCUSSION

Germination

The necessary activities for a seed to complete the process of germination include: water imbibition, germination, radicle entry to the soil and commencement of root growth. This is a simple process in a cultivated seedbed where the soil is wet enough. For oversown (surface sown) seeds the relative humidity of the micro-environment surrounding the seed is important (Campbell, 1973; Campbell and Swain, 1973; Cook, 1980). In this study, there were no significant effects of the various seedbed treatments on germination, an indication of the presence of adequate surface soil moisture at sowing and during the germination phase. This is in agreement with observations made by various workers, that where surface soil moisture is not limiting, oversown seeds germinate well (Cook, 1980; Keya and Kalangi, 1973; Kusekwa, 1977; Lwoga, 1983; Massa and Mannetje, 1982).

However, the legumes differed in their abilities to germinate under the various oversowing conditions: Siratro was superior to the rest of the legume species. This is in agreement with the work by Cook and Lowe (1977) who observed that Siratro seedlings are vigorous and well adapted to a range of soil and climatic conditions.

Establishment and growth

Establishment and growth of the legumes (counts 2 to 4) were significantly poorer in the cultivated treatment than in the burning, hard grazing and normal grazing treatments. The bare soil surface was prone to rapid drying, which resulted in the death of some seedlings. However, it appeared that the main cause of seedling loss was competition from native vegetation, as was also found by Cook (1980). In the burning and hard grazing treatments, which suppressed growth of the native vegetation, establishment and growth of the oversown legumes was much better than in the other treatments. However, as soon as the native vegetation began to regrow it was apparent that competition occurred and the less competitive species such as lucerne and leucaena started to die off. Twining legumes and those that are tolerant to shading, namely Cooper glycine, Siratro, Clitoria and the desmodiums (Humphreys, 1981) did not seem to be greatly affected by the competition from the native vegetation. Tothill and Jones (1977) observed that Siratro was capable of smothering the native vegetation due to its vigour and the build-up of soil nitrogen from nitrogen fixation.

Early survival

Survival of the oversown legume species was indicated by plant count 16, taken 140 days after sowing, and by the percentage legume contributions to total dry-matter yields of the plots 55 weeks after sowing. Survival was influenced by the individual legume's ability to withstand competition from the existing vegetation and to tolerate other environmental stresses, such as moisture stress (Cook, 1980). Siratro showed the greatest survival, followed by Greenleaf desmodium. At the second harvest 6 weeks later, regrowth of the legumes varied, but Siratro was again superior to the other legumes. Leucaena disappeared from all plots before the first harvest.

Fertilizer P application did not have a significant effect on the survival of the legume species, although survival of some of the legumes was slightly increased at higher levels of P application. Rayment et al (1977) observed small increases in dry-matter yield of Siratro/grass pastures with top-dressed P fertilizer at rates up to 60 kg P/ha. Therefore, larger responses could have been obtained at higher P application rates.

CONCLUSIONS

The following conclusions could be drawn from this investigation:

1. Oversowing legumes into native pastures should be carried out when surface soil moisture conditions are likely to be adequate both at and after sowing and preferably for most of the growing period.
2. Competition from native vegetation should be reduced by burning or close grazing in order to aid the establishment of the legumes.
3. Sowing should be timed such that the legumes are well established before the onset of the dry season.
4. More screening work should be done to determine which legume species are suitable for oversowing, i.e. those with seedlings that can establish under oversowing conditions characterised by severe competition and environmental stresses such as severe dry spells.
5. Under the climatic and soil conditions of the trial site, Siratro and Greenleaf desmodium emerged as the most suitable legume species for oversowing in the area.

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HERBAGE SEED PRODUCTION IN SUB-SAHARAN AFRICA, ITS INTEGRATION IN NATIONAL PASTURE RESEARCH AND SEED INDUSTRY DEVELOPMENT AND PROSPECTS FOR REGIONAL SUPPORTING ACTIVITIES

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ABSTRACT

Activities in the fields of herbage seed production and research are relatively underdeveloped throughout sub-Saharan Africa. The only exceptions appear to be Kenya and Zimbabwe, where domestic seed production, mainly of grasses, has reached appreciable levels. Most reports on seed production of forage crops also centre on these two countries, with Kenya concentrating on grasses and Zimbabwe on forage legumes.

There is little application of national seed legislation to herbage seed due to the small scale of commercial operations. Of 25 countries for which information is available, only Kenya reported full implementation of seed quality control measures and advanced levels of herbage seed production and distribution. There are very few opportunities for training in herbage seed production, handling and marketing in sub-Saharan Africa. In the light of this situation ILCA is proposing to implement a herbage seed production, training, outreach and research unit at ILCA headquarters in Addis Ababa. This unit should be a major supporting activity for the regional forage research networks being developed.

INTRODUCTION

Seeds play a vital role in agricultural development for both food crops and forage and pasture crops. The commercial demand for herbage seed, however, depends very much on the emphasis given by governments to pasture development in their livestock policies. It is also a function of the relative priorities assigned to range management and sown pastures. Historically, the emphasis in southern Africa has been on range management, and research on sown pastures or range reinforcement and replacement techniques has started only recently in most sub-Saharan countries. Kenya and Zimbabwe are exceptions, and have a somewhat longer experience in this field. These two countries are also the only ones with a herbage seed industry strong enough to offer sizeable quantities of herbage seed on export markets.

Pasture research in national programmes and in regional and international centres has gained momentum in the last two decades, and many pasture development schemes have been implemented in the region. The corresponding higher demand for herbage seed has not, however, been matched by increased domestic production of herbage seed. Most of the increased demand for herbage seed comes from the state sector or livestock development projects. Such demands are usually met by imports and are thus not conducive to the development of a domestic herbage seed industry. Agricultural subsistence economies are unlikely to develop high and continuous commercial demands for herbage seed. Thus, it is only the comparatively small farming sector with surplus livestock produce and accessible commercial outlets which can develop a genuine demand for herbage seed.

Most African governments have passed legislation designed to regulate the domestic seed market and for phyto-sanitary control of seed imports and exports. This legislation refers to all plant material used for propagation and is the legal framework for all seed-related activities. Based on this legislation the governments have set up seed industry development programmes, which are generally oriented towards the most important food crops and give different priorities to the private and public sectors. In contrast to Asia and especially Latin America, African governments tend to prefer state-controlled seed production rather than to develop private seed enterprises, although there are a few exceptions.

Herbage seed production is generally considered in national seed industry programmes, but is always given rather low priority, and production targets and time frames are not stipulated.

Seed programmes for food crops have a considerable influence on livestock feeding in many African countries since food crop residues are an important source of livestock feed in Africa (Kassila, 1984). The introduction of new crop species and cultivars is likely to change the quantity and/or quality of crop residues produced and will thus influence the performance of livestock. The livestock sectors in national economies therefore have a genuine interest in the use of feed value criteria in the breeding and selection of food crops. The differences in feed values of crop residues even within a given crop species (e.g. sorghum) are considerable and warrant more attention by plant breeders (Reed et al, 1985).

There are few reports of research on herbage seed production from sub-Saharan Africa. Generally such research is not part of coordinated efforts to support production. Kenya and Zimbabwe are the major exceptions.

This paper gives an overview of some national efforts to develop seed production infrastructure. It then highlights some of the research on seed production in herbage crops and finally outlines some recent developments in terms of regional and international activities to support national efforts for increased herbage seed production.

NATIONAL SEED PROGRAMMES AND SOME SELECTED EXPERIENCES WITH HERBAGE SEED PRODUCTION

A national seed industry is composed of several equally important components which extend from cultivar improvement and evaluation by agricultural research institutions, over seed quality control measures carried out by governmental seed certification offices, to seed production and distribution done by public and/or private organisations. In 1979/80, FAO reviewed seed-industry-related activities in 84 countries: 25 in Africa, 24 in Asia, 9 in Central America, 10 in South America, 11 in Europe, 3 in Oceania and 2 in North America (Feistritzer, 1982).

Although most of the countries had active research institutes, few of the developing countries had enough installations for the production, quality control and distribution of improved seeds.

In Table 1 the countries are grouped into three categories according to the development of their food crop and pasture seed industries: those with advanced seed industry, those with fragmentary or pilot-scale operations and those with no substantial seed industry.

Africa ranks last for the three basic seed industry components (cultivar improvement, seed quality control and production and distribution) and for the two crop groups reviewed (food and pasture). There are, however, appreciable differences among African countries in terms of their efforts and achievements. Kenya and Zimbabwe have undoubtedly made the greatest progress in the development of sizeable commercial supplies of improved seed of both food and pasture crops. Their cases are presented in more detail below. Seed-related activities are more recent in Ethiopia, Ivory Coast, Madagascar, Malawi, Nigeria and Zambia. Many African countries did not make substantial efforts to set up a domestic seed industry until the 1970s.

In 1973 the FAO Seed Improvement and Development Programme (SIDP) was implemented. By 1980, SIDP covered 118 countries and another 25 countries cooperated in seed-

Table 1. Production and distribution of quality seed of food and pasture crops, 1979/80.

Crop group	Region (no. of countries)	Category A[1]: Cultivar improvement	Category A[1]: Seed quality control	Category A[1]: Seed production & distribution	Category B: Cultivar improvement	Category B: Seed quality control	Category B: Seed production & distribution	Category C: Cultivar improvement	Category C: Seed quality control	Category C: Seed production & distribution
		Percentage of countries								
Food	Africa (25)	12	4	8	88	80	92	0	16	0
	Asia (24)	33	21	25	58	67	58	8	12	12
	Central America (9)	11	22	0	78	56	89	11	22	11
	South America (10)	90	50	80	10	50	20	0	0	0
	North America (2)	100	100	100	0	0	0	0	0	0
	Europe (11)	100	100	100	0	0	0	0	0	0
	Oceania (3)	33	33	33	33	0	0	33	67	67
	Mean	42	32	36	54	55	57	4	13	7
Pasture	Africa (25)	0	4	4	16	24	8	84	72	88
	Asia (24)	0	4	4	25	21	15	75	75	80
	Central America (9)	0	0	0	11	44	33	89	56	67
	South America (10)	40	30	0	30	60	90	30	10	10
	North America (20	100	100	100	0	0	0	0	0	0
	Europe (11)	100	100	100	0	0	0	0	0	0
	Oceania (3)	33	33	33	0	0	0	67	67	67
	Mean	21	23	19	17	25	21	62	52	60

1. A = advanced.
B = fragmentary or pilot-scale operation.
C = no activity reported.

Source: Feistritzer (1982).

exchange activities. SIDP had a major impact on the discussions about national seed industry development in many African countries with incipient seed activties. Some of the better documented SIDP missions were to Gambia (FAO, 1975), Burkina Fasso (FAO, 1976a), Swaziland (FAO, 1976b), Ethiopia (FAO, 1977), Cameroon (FAO, 1978a), Mauritania (FAO, 1978b) and Nigeria (FAO, 1979). In each case, herbage seed is covered by the national seed programme but obviously no such programme gives first priority to herbage seed.

The Kenyan experience

Oggema (1983), reporting on the Kenyan seed industry, lists five elements necessary for reliable seed production:

1. An assured source of basic seed material;
2. Existence of seed production companies;
3. Existence of regulatory services;
4. Registered seed growers; and
5. Demand for the seed after production.

Kenya has a network of agricultural research stations which continuously provide basic seed of tested cultivars to seed producers. The main stations are the Njoro National Plant Breeding Station, the Thika National Agricultural Research Station and the Katumani Dryland Research Station.

Commercial seed production in Kenya is left to the private sector. There are more than a dozen seed companies, the major ones being the Kenya Seed Company, Njoro Seed Company, East African Seed Company, Simpsons and Whitelaw and Kerchoff. Most of these companies contract farmers to produce seed under supervision. The companies provide the initial seed and also often provide required inputs to facilitate application of appropriate technology.

Kenya has a comprehensive law that controls seed activities. It could be implemented for the seed quality control for which the National Seed Quality Control Services

(NSQCS) at Lanet are responsible.

Any new variety has to be grown in National Variety Performance Trials (NVPT) and in Distinctness, Uniformity and Stability (DUS) trials. The National Seed and Plant Varieties Act does not yet protect plant breeder's rights, and the regulatory services are limited to those crops with a plant breeding research component.

The NSQCS keeps an annual list of seed growers who conform to the seed legislations for the crop they grow. The majority of seed growers are in the Rift Valley and a few in the Central Province. Seed farmers usually sell their seed stocks through the Kenya Farmers Association (KFA), which is an agricultural supply and service organisation with branch offices throughout the country, although there are several other agents and shop-keepers who sell seed on behalf of the companies. It is estimated that the national seed industry meets about 40% of the country's seed requirements, the remainder being landraces.

The Kenya Seed Company (KSC) is of special interest. Based in Kitale, KSC was established in 1956 by a group of farmers in response to demand for seed of improved grass and legume varieties recommended by the Grasslands Research Station in the same town. Hazelden (1982) describes the history and activities of this company some detail. The company has expanded its activities to crops other than pasture but maintains a strong interest in pasture crops, working mainly with grasses, all of them selected from indigenous material. The KSC produces large quantities of *Chloris gayana* (several cultivars) and *Setaria anceps (=sphacelata)*, and smaller quantities of *Panicum coloratum* and *Brachiaria ruziziensis* seed. The company contracts farmers in the Kitale area for approximately 2000 ha of grass for seed annually. Of the domestic sales 15-20% go to small-scale farmers, the rest to large farm units and for export. The company maintains that pasture legumes have never been particularly successful in extensive ley farming. It has sometimes been involved in legume seed production, but only on a small scale. It appears that the Kitale Agricultural

Research Station is the only place where seed of some tropical legumes (*Desmodium* spp.) is still produced (Boonman, 1978a). Lucerne (*Medicago sativa*), a widely used legume, is imported and seed of this and other legumes is also handled by KSC for re-exportation.

The Zimbabwean experience

Seed legislation in Zimbabwe dates back to 1952 when quality testing was made compulsory for the more important crops (Hanssen, 1982). The Seed Services section of the Department of Research and Specialist Services is the official certifying authority. Pasture grass and legume seed multiplication in the Zimbabwean Seed Certification Scheme is done by members of the Zimbabwean Pasture Seed Growers Association (Davis and Hanssen, 1972). Barnes (1968) reported that many farmers in Zimbabwe prefer to establish their own seed-increase plots using small amounts of certified seed. This practice helps them avoid heavy expenses and acquaints many farmers with the technical problems related to herbage seed production.

Pasture seed is commonly harvested by hand. Seed yields are reasonable due to adequate fertilizer and plant protection inputs. Commercial emphasis was and still is on the production of grass seed. *Eragrostis curvula* (Weeping Lovegrass) is widely used. *Cynodon plectostachyus* (African Stargrass) is one of the African grasses that have been successfully introduced to other continents. However, like *Pennisetum* spp., it is propagated by means of root splittings or rhizomes. Several well-seeding *Paspalum* spp. are also widely used and commercialised in Zimbabwe (*P. plicatulum, P. quenoarum, P. notatum*), along with *Panicum maximum* and *Chloris gayana*. Seed of Zimbabwe Sudan grass (*Sorghum verticilliflorum*) is also produced.

Excellent progress has been made in Zimbabwe in the development of pasture legumes for use in mixtures with grasses. *Trifolium semipilosum* (Kenya white clover), *Lotononis bainesii* and *Desmodium intortum* (Greenleaf) showed particular promise in the early years of commercial forage legume utilisation (Barnes, 1965). This work with legumes, which included pest resistance, breeding for cultivar evaluation and selection and production of rhizobium inoculants and seed production, was started in the early 1960s (West, 1964). At same time, Zimbabwe developed probably the only infrastructure of practical relevance in the subcontinent for the production of rhizobium inoculants for forage legumes. This reflects the importance given to pasture legumes and production of their seed in Zimbabwe. Commercial experience with an impressive range of pasture legumes for many ecological conditions has been gained: *Trifolium repens, T. pratense* and *Medicago sativa* were used under irrigation in cool, high elevation areas. The African clovers *Trifolium semipilosum* and *T. rueppellianum* competed with *T. repens* in rain-fed, legume-based pastures in the high-rainfall highlands. *T. semipilosum, Cajanus indicus, Desmodium discolor* and *D. intortum* were used in the high-rainfall main cropping areas to sustain livestock production. Some of these legumes were also used extensively for oversowing in range improvement.

A widely used method of range improvement is to rest the range (veld) during the whole of the growing season (Gill, 1938). After the pasture has set seed in autumn, stock are allowed to graze during winter. The animals thus help the seed to be shed and to be trampled into the soil. After commercial pasture seed became available, such range improvement methods could be complemented with oversowing techniques.

The Zimbabwean seed industry has recently developed a tree seed centre at the Forest Research Centre to provide seed to the member countries of the Southern Africa Development Co-ordinating Conference (BBC, The Farming World, June 11-13, 1985). This initiative is particularly important for the support of regional efforts in agroforestry and sylvi-pastoral activities.

The Zambian experience

An FAO grassland mission to Northern Rhodesia (Zambia) in 1955 recommended that a country-wide programme of grass and legume seed production should be set up (FAO, 1955). This recommendation was made on the basis of numerous reports from individual farmers and from experiment stations who were successfully using sown pastures. However, the national seed legislation, the basis of any seed industry development, was passed only after independence.

Plant breeding and agronomic evaluation is the responsibility of the Research Branch of the Ministry of Agriculture and is coordinated from the Mount Makulu Research Station at Chilanga, which was established in 1953. The Zambia Seed Company (Zamseed) was created to deal with the production, processing, storage and nation-wide supply of high-quality seed, at a minimum cost to the consumer (Wellving, 1983). The state-controlled Zamseed is responsible for multiplying and distributing cultivars released by the Cultivar Release Committee. Zamseed is also responsible for all seed imports and exports. It carries out the seed production through the Zambia Seed Producers Association (ZSPA). Much of the seed processing, especially of the large grains such as maize, is done on the farms. Seed is tested and certified by the Seed Control and Certification Institute (SCCI) at Mount Makulu. Zamseed furnishes the certified seed to retailers such as Namboard, cooperative unions and others.

While the Zambian seed industry reportedly meets about 40% of the national requirements for seed of improved cultivars of the major food and industrial crops (the rest being met by landraces), the production of herbage seeds is lagging behind (Cranford, 1975). Nonetheless, some commercial seed of nine pasture legumes was reported to be available (Cranford, 1978), including *Rhynchosia sublobata* (cv. Mukolo), an indigenous accession. The most important legume species an offer were *Stylosanthes guianensis, Macroptilium atropurpureum, Neonotonia wightii, Desmodium* *uncinatum* and *Leucaena leucocephala*. Certified seed of grasses (*Eragrostis curvula, Cenchrus ciliaris, Setaria anceps, Chloris gayana and Panicum maximum*) was also available.

A comprehensive seed production handbook has been published by the Zambia Department of Agriculture (Welving, 1984), giving valuable practical advice to seed growers and indicating seed yields that are likely to be achieved with a number of pasture legumes under Zambian conditions.

Herbage seed production in West Africa

Production of herbage and pasture seed has received little attention from national agricultural research systems in anglophone West Africa (Adegbola, 1971), despite early reports on pasture research in Nigeria (Ahlgreen et al, 1959; Rains, 1963) and Ghana (Evans, 1961) emphasising the importance of an adequate supply of seed in making the research results applicable. Very little work has been reported from Sierra Leone, Liberia or the Gambia on forage crop introduction and evaluation. Sierra Leone has recently started an effective Seed Multiplication Project (Kreul, 1984) but this deals only with rice seed at present. However, production of seed of other crops, such as pasture crops, could be integrated into the project relatively easily if needed. The Nigerian National Seed Service also concentrates mainly on food crops (Joshua and Singh, 1982).

There is a considerable amount of information of the suitability and performance of herbage species, both indigenous and introduced, in West Africa. For example, McIlory (1962) established lists of grasses and legumes adapted to the guinea savannah, the derived savannah and the rainforest ecosystems in West Africa, based on agronomic evaluations. The legumes listed included the genera *Stylosanthes, Centrosema, Calopogonium, Pueraria* and *Neonotonia*. ILCA has successfully devised feed production systems in the humid and subhumid ecosystems of Nigeria using

Stylosanthes spp., *Gliricidia sepium* and *Leucaena leucocephala* (Sumberg and McIntire, 1985). Sumberg (1985) also reported on the seed production of *Gliricidia sepium*.

The situation in francophone West Africa is generally similar to that in anglophone West Africa. Comprehensive reports on pasture research are available; for example, Borget (1971) reported the results of 5 years' work at the Institut de Recherches Agricoles Tropicales in Senegal, Bourkina Fasso, Niger, Dahomey, Cameroon, Gabon and the Central African Republic. A wide range of grasses and herbage legumes were found to be suitable for commercial use in pasture development, but none of these countries has yet established a domestic herbage seed production industry. All have implemented national seed production programmes with emphasis on food crops.

The same is also true of Mali (Anon., 1973), where a large seed multiplication scheme was established in 1977 (Giacich and Toure, 1982) dealing with the major food crops. It appears that the Ivory Coast was the first francophone West African country to implement a pilot scheme on pasture and pasture seed development (Anon., 1971), although Madagascar has undertaken similar efforts.

Other herbage seed production initiatives

The seed industry in Sudan, described by Joshi (1978), concentrates on major food crops. However, Douglas (1976), when reviewing the national seed programme, expressed the need to integrate pasture seed production into the scheme. In Ethiopia the seed production industry is state controlled. Seed is produced by the Ethiopian Seed Corporation, which was set up in 1979 and is affiliated to the Ministry of State Farms. The Corporation produces relatively small amounts of seed of herbage species (*Vicia villosa* ssp. *dasycarpa*, *Avena sativa*) for use on state farms and for sale to institutes. More recently, commercial quantities of seed of some herbage species have been produced by the Arsi Rural Development Unit and the Ministry of Agriculture, Soil and Water Conservation Department and Feeds and Forage Project.

In Tanzania there is virtually no commercial-scale production of herbage seed. Multiplication activities are restricted to government experiment stations (Rwebangira, 1978), a situation found in many other countries in sub-Saharan Africa.

PROSPECTS FOR REGIONAL SUPPORT OF HERBAGE SEED PRODUCTION

> *"A country which does not produce its own agricultural seed is a country without agricultural technology of its own and ultimately a country without sovereinty"* (Rolon Anaya, 1977).

National efforts to increase domestic production of herbage seed can be decisively enhanced by regional and international supporting activities, which include training, exchange of germplasm, provision of documentation and consultancies. At present such supporting activities do not exist in Africa. CIAT, a CGIAR-supported research centre based in Colombia, appears to be the only institution in the developing world that provides services of this kind. However, CIAT's supporting activities are intended mainly to service the needs of countries in Latin America, and its activities would have to be increased substantially to meet the needs of Africa.

Training staff in seed technology and research can provide national programmes with leaders for their domestic herbage seed production projects. Research, training and outreach activities on a regional basis can improve communications, increase the uniformity of seed standards and procedures and increase the flow of germplasm among the countries of the region.

ILCA is developing such support facilities at its headquarters in Addis Ababa, Ethiopia. The Centre recognises that effective herbage seed production, processing and marketing programmes in its mandate countries are essential to the success of the pasture research being conducted by ILCA. Seed certification schemes run by the national programmes are a logical step in the use and maintenance of promising plant germplasm.

The objectives of the Herbage Seed Unit that will be set up at ILCA HQ will be to:

* Train staff from private and public institutions, primarily in sub-Saharan Africa, in herbage seed production, drying, processing, storage, marketing, quality control and seed programme development;

* Provide consultancies and to collaborate in management and technical aspects of herbage seed programmes and seed industry. The major focus of these activities will be to increase the availability of seed to farmers. Whenever possible, the Herbage Seed Unit will draw upon African expertise and former trainees to address local problems;

* Multiply and distribute sufficient seed of high quality to ILCA's field programmes for primary testing of germplasm in different ecological zones in Africa, and to assist in the propagation and introduction of the commodities of other international agricultural research centres (IARCs) in sub-Saharan Africa;

* Help to develop the framework of policy decisions needed to build stronger national seed programmes and seed enterprises in the region; and to

* Strengthen the capabilities of the seed industry in the target countries, to enable them to produce and supply high-quality seed. In this, the Herbage Seed Unit will concentrate on commodities in which ILCA has major activities, such as forage legumes, or in which ILCA has relay responsibilities, such as for materials produced by other IARCs.

A symposium held in Zimbabwe in October 1984 proposed that a forage research network be established for eastern and southern Africa (PANESA), to be sponsored by the International Development Research Centre (IDRC). The United States Agency for International Development (USAID) has since shown interest in expanding this network to cover West Africa. The activities of this network will soon be starting and there will be a need to increase ILCA's seed production capacity to produce the seed needed by the network participants. PANESA will also be an important channel for the outreach activities proposed for the Herbage Seed Unit.

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A SMALLHOLDER APPROACH TO STYLO SEED PRODUCTION IN NIGERIA

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ABSTRACT

The cost of producing Verano stylo and Cook stylo seeds on a local farm was studied at Shika. Labour inputs and costs of all field operations, namely hand stumping, hand piling or heaping, burning, cleaning, cultivation, sowing, fertilizing, weeding, seed harvesting and cleaning, were determined. Data showed that it would require about 180 man-days and N 2400 to produce Verano stylo seed from one hectare of land in the first year, but the figures would be lower in the second and subsequent years. Labour input and field operations costs are higher for production of Cook stylo seed. Where machinery is used in harvesting, both Verano and Cook stylo seed cost less to produce. Seed cleaning, which is done manually, is the most expensive operation, followed by seedbed preparation.

INTRODUCTION

The feeding value of natural grasses in Nigeria is normally high early in the wet season, but is extremely low in the dry season. Legumes, on the other hand, remain much higher in quality during the dry season (Blair-Rains, 1963). The introduction of legumes into the natural grassland would therefore improve the quality of the pasture in the dry season. Legumes can be introduced into natural grasslands by oversowing (Blair-Rains, 1963), drilling seeds in harrowed strips (Haggar et al, 1971) or by feeding seed to grazing cattle (Foster, 1961). Alternatively, blocks of pure legumes can be established adjacent to rangeland, and these can be grazed as a supplement to natural grassland (Haggar et al, 1971).

Large-scale use of legumes in most African countries is hampered by lack of seed. Most African countries depend almost entirely on imported seed, but lack of foreign exchange has forced some of these countries to virtually stop pasture development. If adapted legumes are to be used, African countries will have to develop their own seed-production systems, especially for such popular legumes as *Stylosanthes hamata*.

In order to provide a guide as to how much it would cost to produce seed of some legumes, a small, in-depth on-farm study was undertaken.

MATERIALS AND METHODS

In 1977, a 10-hectare farm was acquired from a local farmer at Shika. The land had been under fallow for more than 8 years and had reverted to true savanna. The vegetation consisted of an *Isoberlinia - Hyparrhenia* association with *Andropogon* spp. being co-dominant. Other common grass species were *Pennisetum polystachyon, Cymbopogon giganteus* and *Brachiaria* spp. The soil was sandy loam.

The natural vegetation was cleared of shrub growth. Land clearing involved hand stumping using hoes and axes, hand piling or heaping, burning and clearing of unburnt material and re-burning it. Seedbed preparation involved ploughing and harrowing, using a hired tractor. Other operations were sowing, fertilizer application, hand weeding, hand harvesting, sweeping seed from the ground, manual seed cleaning, brushcutting, raking and baling. The labour inputs and cost of each field operation were determined based on 10 labourers out of the many that were employed in each field operation.

After ploughing and harrowing the land, 10 kg of clean, hot-water-treated Verano stylo seed were sown per hectare. Seed of Verano was sown into 5 hectares of the prepared land and the remaining 5 hectares were sown to Cook stylo at the rate of 5 kg seed/ha. Single superphosphate fertilizer was applied at the rate of 31.2 kg P/ha one day after sowing was completed.

Weeding was carried out by hand-hoeing twice when the stylo plants were 6 and 10 weeks old. Verano stylo seed was hand-harvested using sickles, beginning in the first week of December and lasting for 2 weeks.

The first harvest of Cook stylo started in late December. Ripe heads were hand-picked by women. The seed-heads were dried on a concrete floor, threshed, winnowed and further cleaned. The clean seed was weighed, and the mean weight of seeds harvested per day was determined. The Cook stylo stands from which seed had been harvested were brush-cut and the cuttings were raked up and baled. Ripe seeds of Cook and Verano that had fallen on the ground were swept up with brooms by women and cleaned repeatedly. This method of harvesting is termed Method I. The stylo stands were not grazed.

Under Method II, the established pastures of Verano stylo and Cook stylo were grazed between June and mid August, after which the paddock was closed to allow seed formation and maturation. In December, the field was brush-cut, raked and baled. Seed was recovered from the ground using the same method as described above.

RESULTS

Labour inputs and costs of all field operations, including bagging of seed and transportation, are presented in Tables 1 and 2. The Tables show that harvesting, together with seed cleaning, was the highest cost item in the first year Verano stylo (44.5% of the total cost). The supervisor's wages, stumping and weeding represented 20.3, 10.6 and 8.5%,

Table 1. Labour inputs and cost of producing Cook stylo and Verano stylo under Method I at Shika.

Operations	---Verano--- Man-days	N/ha[1]	---Cook--- Man-hours	N/ha
1st year				
Stumping (manual)	15	250	15	250
Piling or heaping (manual)	5	50	5	50
Burning (2 x)	0.1	5	0.1	5
Clearing unburnt stumps	2	15	2	15
Ploughing (hired tractor)	1	40	1	40
Harrowing (hired tractor)	0.5	20	0.5	20
Seed (10 kg/ha @ N 8.00/kg)	-	80	-	80
Basal nitrogen (100 kg nitrochalk/ha)	-	16	-	16
Single superphosphate (400 kg/ha)	-	64	-	64
Seed and fertilizer broadcasting	1	10	1	10
Weeding (2 x) in Verano stylo	8	200	-	-
Weeding (1 x) in Cook stylo	-	-	4	100
Harvesting with sickles (Verano)	10	150	-	-
Harvesting seed heads by hand (Cook)	-	-	100	375
Seed sweeping and cleaning	120	900	-	-
Threshing and cleaning (manual)	-	-	100	375
Seed recovery	-	-	50	200
Jute sacks (12 or 3 @ N 4 each)	-	48	-	12
Bagging	1	12	-	10
Transportation of inputs and seed	0.5	20	0.5	20
Supervisor's wages 4 mo @ N 120	-	480	-	480
Hay production	1.8	130	2.5	160
Total	165.9	2490	281.6	2282
2nd year				
Single superphosphate (100 kg) + broadcasting	1	25	1	25
Weeding (2 x)	10	260	-	-
Weeding (1 x)	-	-	5	130
Harvesting with sickles	12	180	-	-
Harvesting ripe seed heads (manual)	-	-	130	500
Sweeping seed and clearing	160	1200	-	-
Threshing and cleaning	-	-	130	500
Seed recovery and cleaning	-	-	100	400
Jute sacks (16 or 4 @ N 4.00)	-	64	-	16
Bagging	1	16	1	12
Transporation of inputs and seed	0.5	20	0.5	20
Supervisor's wages (3 mo @ N 120)	-	360	-	360
Hay production	1.8	130	2.7	240
Total	186.3	2255	370.2	2203

1. 1 N = US$ 1.117 (19/9/85).

Table 2. Labour inputs and cost of producing Cook stylo and Verano stylo under Method II at Shika.

Cost components	--Verano-- Man-days	N/ha	---Cook--- Man-hours	N/ha
Seedbed preparation	23.6	380	23.6	380
Seed and fertilizers	-	160	-	160
Seed and fertilizer broadcasting	1	10	1	10
Brushcutting	0.5	35	1	50
Raking	0.1	10	0.2	10
Baling	0.2	15	0.3	20
Gathering, loading and tranporting bales	1	20	1	20
Seed sweeping and cleaning	100	750	150	870
Supervisor's wages (2 mo @ N 120)	-	240	-	240
Transportation of inputs and seed	0.5	20	0.5	20
Total	126.9	1690	177.6	1840
2nd year				
Single superphosphate	-	15	-	15
Broadcasting superphosphate	0.5	5	0.5	5
Brushcutting	0.5	35	1.0	50
Raking	0.1	10	0.2	15
Baler twine	-	50	-	100
Baling	0.2	15	0.5	30
Gathering, loading and transporting bales	1	20	1	30
Seed sweeping and cleaning	120	900	200	1250
Supervisor's wages (2 months)	-	240	-	240
Transportation of inputs and seed	0.5	20	1	40
Total	122.8	1410	204.2	1775

respectively, of the total production cost. In Cook stylo, the order of costs were the same as in Verano stylo. Seed harvesting together with seed recovery from the ground cost N 950/ha and represented 44.8% of the total cost.

In the second-year crops, the main cost items for the two species were again hand-harvesting plus seed recovery and the supervisor's wages, followed by weeding. Harvesting together with seed recovery represented 64.9 and 68.5% for Verano stylo and Cook stylo, respectively.

Many more man-days of work were required to produce seed from the 2-year-old crop than from the first-year crop. Harvesting, together with seed cleaning, required more labour than any other field operation. In both years, Cook stylo required more labour than Verano stylo.

Under Method II (Table 2), seed recovery was the highest cost item in both species, followed by seedbed preparation in the first year and supervisor's wages in the second year.

Seed production was cheaper from Method II than from Method I. Similarly, labour inputs in both years were lower in Method II than in Method I. Labour for seed recovery in year one comprised 78.8 and 84.4% of the total labour inputs for Verano stylo and Cook stylo, respectively. In the second year, labour for seed recovery had increased to 95.3 and 97.9% of the total labour inputs for Verano and Cook stylo, respectively. A summary of the labour inputs is presented in Table 3.

Table 3. Labour inputs in the two methods of Verano stylo and Cook stylo seed production.

	Labour inputs/ha (man-days)			
Year of	---Method I---		---Method II---	
production	Verano	Cook	Verano	Cook
1	165.9	281.6	126.9	177.6
2	186.3	370.2	122.8	204.2

Under both systems, seed yields were higher in the second year than in the first for both species (Table 4). Method I gave higher seed yields than Method II for both species, and this is reflected in the revenues derived from sales (Table 5).

Table 4. Seed and hay yields in Methods I and II (kg/ha and bales/ha).

Year of production	Product	--Method I--		--Method II--	
		Verano	Cook	Verano	Cook
1	Seed (kg/ha)	600	400	500	350
2	Seed (kg/ha)	500	600	600	500
1	Hay (bales/ha)	250	450	200	400
2	Hay (bales/ha)	300	550	250	500

The cost of producing Verano and Cook stylo on per hectare and per kilogram bases is shown in Table 6. Mean seed production costs for the first 2 years was over ₦ 1420/ha and ₦ 1607/ha for Verano and Cook stylo, respectively. The cost of producing 1 kg of seed was higher in the first year than in the second. Within species differences were small for both methods of seed production.

Profit margins per hectare in the two methods of seed production are presented in Table 7. In Method I, profit margins more than doubled in the second year of production compared with the first year. Only in the first year was the profit margin in Method II higher than in Method I.

Table 5. Expected revenue from clean seed and hay (N/ha).

		Revenue (N/ha)			
Year of		---Method I---		---Method II---	
production	Product	Verano	Cook	Verano	Cook
1	Seed*	3000	3200	2500	2800
2	Seed	4000	4800	3000	4000
1	Hay**	375	675	300	600
2	Hay	450	825	375	750
1	Total	3375	3875	2800	3400
2	Total	4450	5625	3375	4750

* Verano and Cook stylo seeds sold at N 5.00 and N 8.00 per kilogram respectively.

** Bales of hay sold at N 1.50 each.

Table 6. Cost of producing Verano stylo and Cook stylo (N/ha and N/kg).

Year of	---Method I---		---Method II---	
production	Verano	Cook	Verano	Cook
	N/ha			
1	2360	2122	1560	1680
2	2125	1963	1280	1535
	N/kg			
1	3.93	5.26	3.12	5.09
2	2.66	3.27	2.13	3.07

Table 7. Profit margins from the two methods of Verano stylo and Cook stylo seed production (N/ha).

Year of production	---Method I---		---Method II---	
	Verano	Cook	Verano	Cook
	---------------N/ha---------------			
1	885	1593	1110	1560
2	2195	3422	1965	2975

DISCUSSION

Pasture legume seed production has not been reported anywhere in Nigeria except at Shika (Agishi, 1978; 1982). The few earlier studies indicated that it costs more to produce legume seeds than grass seeds. Difficulties of under-costing associated with the studies carried out by government institutions were avoided by carrying out the project on a farm outside the research institute. Many items of production were carefully costed in order to arrive at realistic seed-production costs.

The total cost of seed production appears high but could be substantially reduced by using land already in cultivation and by eliminating the supervisor's role. The apparently lower profit margins obtained in Method II are due to no value being included for the benefits the animals derived from grazing. The cattle grazed the stylo seed crops from June to August when there is a shortage of labour for weeding. The money saved by not having to employ labourers for weeding during this period could be used for other farm operations.

In the fodder-bank system, where 4 hectares of land are planted to stylo and fenced, a part of the pasture could be closed for seed production. The farmer could use part of the seed produced on his farm to expand his fodder bank and sell the rest. If this approach is adopted, these agro-pastoralists could form a nucleus for pasture seed production in this country.

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GLIRICIDIA SEPIUM AS DRY SEASON FEED FOR GOAT PRODUCTION IN NIGERIA

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ABSTRACT

An experiment comprising five trials was conducted during the dry season (November through April) to assess the nutritional value of dried *Gliricidia sepium* leaves (GRL) both fed alone and supplemented with cassava peel. The ability of the leaves to meet the N requirements of West African dwarf (Fouta Djallon) goats was examined.

Gliricidia leaves contain about 3.3% N and are available throughout the year. The dried leaves were stored through the dry season without deteriorating and thus can serve as a feed reserve.

Goats consumed up to 477 g of GRL DM/day when the diet was supplemented with cassava peel. Nitrogen in GRL was about 58% digestible.

INTRODUCTION

The major constraint to livestock production in Nigeria is the shortage of dry season feed, particularly shortages of forage and cheap sources of supplementary N.

Tree legumes are very good sources of browse in Nigeria. *Gliricidia sepium* is a fast growing, perennial leguminous tree which supplies fodder. It also fixes atmospheric N, although only 13 kg N/ha per year (Duhoux and Dommergues, 1984), and thus can serve as a cheap alternative to fertilizer N.

The nutritive value of *G. sepium* as animal feed has been studied by Carew (1982), Mba et al (1982), Sumberg (1984) and Onwuka (1980), among others. These studies indicated that *G. sepium* contains between 3.2 and 4.2% N and can also be used as a source of supplemental energy for animal feeding.

This paper examines the ability of *G. sepium* to meet the protein and energy requirements of West African dwarf goats and the possibility of drying and preserving *G. sepium* leaves for feeding to animals during the dry season.

MATERIALS AND METHODS

Gliricidia sepium leaves (GRL) were collected from the National Horticultural Research Institute (NIHORT), Ibadan, and the University of Ibadan Teaching and Research Farm and oven-dried at 50-60^{o}C for 48 hours. Cassava peel (CAP) was collected from IITA, Ibadan, and oven-dried for 3-4 days at the same temperature. The GRL and CAP were fed to West African dwarf goats in the dry season in different combinations, with GRL forming 0, 25, 50, 75 and 100% of the diets, the remainder being CAP. After mixing, the diets were ground in a milling machine.

Twenty West African dwarf (WAD) goats obtained from the T & R farm of the University of Ibadan were used in the feeding experiment. The animals were fed twice daily and kept in metabolism cages for 21 days for each trial, i.e. 14 days preliminary feeding and 7 collection days.

The proximate composition of dried GRL and CAP, faeces and urine were determined according to AOAC (1975) methods. All results are expressed on DM basis and were subjected to statistical analysis using Snedecor and Cochran's (1968) procedure for analysis of variance. Statistical significance between treatment means was determined using Duncan's (1955) multiple range test.

RESULTS AND DISCUSSION

When fed to the goats, the acceptability of the ground rations was very low and they caused diarrhoea: as a result, the leaves and cassava peel were then fed whole.

The proximate chemical compositions of the GRL and CAP are shown in Table 1. Gliricidia leaves had high crude protein content (21% CP or 3.36% N) and the protein was about 58% digestible. The crude fibre was upto 68% digestible. The gross energy value of GRL (about 4.35 kcal/g) was quite high. Cassava peel contained less CP (6%) and less gross energy (3.9 kcal/g) but more crude fibre.

The levels of macro- and micro-nutrients in GRL were quite high, although levels of Cu, Zn, P and Cl were lower than in some other forage legumes assayed by Onwuka (1980).

Table 2 shows the N and energy utilisation, weight changes and dry-matter intake by the goats. Nitrogen balance improved significantly ($P<0.05$) when GRL was supplemented with 25% CAP, but decreased with higher levels of CAP supplementation. The negative N-balance (-0.07) with the 100% CAP diet indicates that the animals were losing more N than they were taking in and was due probably to the low level of protein in cassava peels.

A mean MFN (metabolic faecal N) value of 0.30 g/100g DM intake was obtained from the regression of faecal N (g/kg DMI) on N intake (g/kg $W^{0.734}$ per day), and an EUN (endogenous urinary N) value of 0.03 was obtained by regressing urinary N on absorbed N (all in g/kg $W^{0.734}$ per day). There were highly significant ($P<0.05$) correlations between these parameters.

In this study, a biological value (BV) for the protein of 76.6 was observed. Using the factorial method, 0.5g/kg $W^{0.734}$ per day digestible crude protein (DCP) was found to be required for maintenance, while regression of N balance on N intake showed a DCP requirement of 3.85g/kg $W^{0.734}$ per day for weight gain. An average of 72 kcal ME/kg $W^{0.734}$ per day was required for maintenance while 184.53 kcal ME/kg $W^{0.734}$ per day was required for weight gain.

Table 1. Proximate chemical composition of *Gliricidia sepium* leaves and cassava peel.

Component	Content (g/100 g DM)	
	Gliricidia leaves	Cassava peel
Dry matter	34.5	
Crude protein	20.69	5.94
Crude fibre	23.08	31.75
Ether extract	4.95	4.10
Ash	7.69	9.00
Nitrogen-free extract	43.59	49.21
Organic matter	92.31	91.00
Total digestible N	48.18	55.33
Ca	0.95	
P	0.30	
Na	0.03	
Mg	0.46	
K	3.36	
Zn (ppm)	21.0	
Fe (ppm)	300	
Mn (ppm)	80	
Cu (ppm)	5	
Gross energy (kcal/g)	4.35	3.90

The DM consumption values obtained in this study are comparable to those of 233.8 to 294.8 g/day obtained by Mba et al (1982) but lower than the 466 g DM obtained by Carew (1982) for *Gliricidia* sp. These researchers, however, fed fresh GRL. Some 4- to 5-month trials have been designed to compare dry and fresh feeds, if the materials are available.

Table 2. Summary of nitrogen and energy utilization data, weight changes and dry matter intake of West African dwarf goats fed gliricidia leaves.

	100% CAP	25% GRL:75% CAP	50% GRL:50% CAP	75% GRL:25% CAP	100% GRL
Nitrogen intake (g/kg $W^{0.734}$ per day)	0.40 (0.05)^{b}	1.00 (0.14)^{a}	0.62 (0.09)^{ab}	0.83 (0.29)^{ab}	0.80 (0.25)^{ab}
Nitrogen balance	-0.07 (0.03)^{b}	0.23 (0.14)^{ab}	0.31 (0.03)^{a}	0.39 (0.21)^{ab}	0.29 (0.08)^{ab}
Urinary nitrogen	0.02 (0.01)^{b}	0.13 (0.06)^{ab}	0.05 (0.01)^{ab}	0.11 (0.05)^{ab}	0.17 (0.07)^{a}
Absorbed nitrogen	0.14 (0.05)^{b}	0.55 (0.13)^{a}	0.45 (0.05)^{ab}	0.60 (0.24)^{a}	0.56 (0.17)^{a}
Faecal nitrogen (g/kgDMI)	10.66 (0.65)^{bc}	10.03 (0.28)^{bc}	7.68 (0.68)^{c}	11.10 (1.12)^{b}	14.09 (0.70)^{a}
Liveweight change (g/day)	-125 (61.98)^{a}	77.5 (18.43)^{a}	38.67 (22.23)^{a}	63.00 (83.67)^{a}	17.5 (115.93)^{a}
Dry-matter intake (g/day)	295 (54.67)^{a}	476.58 (38.94)^{b}	244.0 (41.48)^{a}	245.75 (78.79)^{a}	176.83 (72.75)^{a}
ME intake	45.3 (3.75)^{c}	135.9 (10.46)^{a}	84.9 (12.90)^{b}	66.6 (27.29)^{bc}	35.2 (14.78)^{c}
N digestibility coeff. (apparent)	-12.06 (6.78)^{b}	35.63 (8.07)^{a}	57.18 (3.77)^{a}	54.03 (0.96)^{a}	57.72 (1.85)^{a}

Means in the same row with same superscript are not significantly different ($P<0.05$).
CAP = cassava peel; GRL = *Gliricidia sepium* leaves.
Figures in parentheses are standard errors.

Since cassava peel contains cyanide (Devendra, 1981), an alternative source of supplementary energy will be used.

The results of this study indicate that *Gliricidia sepium* leaves fed alone are not adequate as a dry-season feed for goats, but may be adequate when supplemented with an energy source. According to Munro and Naismith (1953) and Sibbald et al (1956), there is an optimum energy level for each protein level of a diet at which maximum N retention is obtained.

The dried gliricidia leaves used these trials did not show any deterioration in quality during the dry season.

CONCLUSIONS

Gliricidia sepium has a high nutrient content and has great potential for animal feeding, especially in the dry season in sub-Saharan Africa when the natural vegetation is of poor nutritive value.

The feeding value of gliricidia can be increased by supplementing it with an energy source, such as crop or agro-industrial byproducts.

Drying gliricidia leaves is a good means of feed storage, especially in village communities where cut-and-carry is practised and forage is scarce in the dry season. Fodder banks of gliricidia or other forage legumes could be established, especially in areas where dry season fire is a great threat.

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VALUE OF A FORAGE LEGUME COMPONENT IN SUMMER BEEF FATTENING SYSTEMS IN MALAWI

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ABSTRACT

Two pasture systems for fattening beef cattle in summer were studied: (1) a pure sward of Rhodes grass (*Chloris gayana*) plus 40 kg N/ha and (2) a mixture of Rhodes grass and Silverleaf desmodium (*D. uncinatum*). The forage yields of the two pastures were similar. The average daily liveweight gain of heifers on the grass-legume pasture was higher than that of heifers on the Rhodes-grass pasture, due to the higher crude protein content of the mixed sward.

INTRODUCTION

Nitrogen is one of the major plant nutrients on which plant growth depends (Russel, 1966). In Malawi the cost of fertilizer nitrogen has increased considerably in the past decade. Between 1972/73 and 1983/84 the price of ammonium sulphate (21% N) and calcium ammonium nitrate (26% N) in Malawi increased by 92 and 100%, respectively. Between 1983/84 and 1984/85 the price of these fertilizers increased further by 29 and 19%, respectively, and prices are expected to continue to increase.

In smallholder farming systems, the use of fertilizer N is largely restricted to cereal crops, such as maize, that are used for human food. Thus there is a strong case for introducing tropical forage legumes into pastures in smallholder farming systems in Malawi.

Forage legumes provide an alternative source of N for pasture growth through their ability to fix atmospheric N, as well as increasing the nutritive value of the forage produced. The dry-matter yield of a pasture containing *Stylosanthes guianensis, Desmodium intortum* and *Chloris gayana* was reported to be equal to that of a *C. gayana* pasture fertilized with 448 kg of ammonium sulphate per hectare. Thus the legumes fixed the equivalent of at least 94 kg N/ha annually (Department of Agriculture, 1961; Thomas, 1973).

It is difficult to establish and maintain legumes in association with vigorous stoloniferous grasses such as *C. gayana* and *Cynodon* sp. However, Thomas (1976) and Dzowela (unpublished) found that *Desmodium uncinatum, Macroptilium atropurpureum* and *Centrosema pubescens* could be successfully established and could maintain a stand beyond the second year in association with these grasses.

Addy and Thomas (1977) demonstrated substantial levels of beef production of 369, 525 and 539 kg/ha at 2.5, 5.0 and 7.5 livestock units per hectare, respectively, from improved, fertilized pastures. The only comparable data for a legume-based pasture system are those reported by Dzowela (1984), who found that steers on a *Stylosanthes*-sp.-based natural grassland lost less weight than steers on a pasture that did not contain legume.

This study was undertaken to investigate the beef production potential of a Rhodes-grass pasture fertilized with inorganic N and of Rhodes grass grown in association with *D. uncinatum*.

MATERIALS AND METHODS

Two treatments were investigated: Rhodes grass in pure stand fertilized with 40 kg N/ha, and a mixed sward of Rhodes grass and Silverleaf desmodium (*D. uncinatum*). The swards were established in the 1981/82 growing season on 1.5 ha paddocks, with 3 replicates. Each paddock received 16.6 kg P/ha annually.

The 'put-and-take' grazing system (Mott and Lucas, 1952) was used to maintain optimum grazing pressure throughout the season. Eight 2-year-old Malawi Zebu 'tester' heifers were kept in each paddock throughout the growing season in 1982/83, 1983/84 and 1984/85. The animals were kept on the pasture from the beginning of the growing season in November/ December until they stopped gaining weight, which coincided with the beginning of the dry season in May/June. Additional animals, 'grazers', were put into the paddocks if there was an excess of forage.

Each paddock was divided into four parts to facilitate rotational grazing. The animals spent one week in each quarter, and the 'testers' were weighed every 28 days. The forage was sampled before the paddocks were grazed, and the samples were separated by hand into grass and legume components before being dried in the oven at 65 ^{o}C for dry-matter determinations. Oven-dry samples were ground to pass through a 1 mm screen, and were analysed for crude protein (CP) content and *in vitro* dry-matter digestibility.

RESULTS AND DISCUSSION

The forage dry-matter yields of the two pastures were similar over the three seasons (Table 1). The N status of the soil before and after the trial was also similar (Table 2), which indicates that all the growth was produced on the fertilizer N applied or on the N fixed by the legume.

The heifers on the grass-legume sward had significantly higher average daily liveweight gains in 1982/83 and 1984/85 than those on the pure Rhodes grass sward ($P < 0.05$), but there was no significant difference in 1983/84 (Table 3). There were no significant differences in the total liveweight gain or number of grazing days in any of the three seasons. However, the total liveweight gain per hectare tended to be higher in the grass-legume treatment than in the pure grass treatment.

Table 1. Forage dry-matter yields of Rhodes grass and Rhodes grass-Silverleaf desmodium pastures, 1982/83 to 1984/85.

Pasture	DM yield (t/ha)		
	1982/83	1983/84	1984/85
Pure Rhodes grass	11.33	14.61	11.76
Rhodes grass plus Silverleaf desmodium	11.17	14.71	12.49

Table 2. Soil nitrogen status before and after three seasons of Rhodes grass and Rhodes grass-Silverleaf desmodium pastures.

Pasture	Prior to treatments November 1982	After treatments May 1985
Pure Rhodes grass	0.32	0.31
Rhodes grass plus Silverleaf desmodium	0.29	0.30

While the digestibility of the forage from both treatments was the same (57%), the grass-legume mixture contained significantly more CP (12.57%, compared with 9.43% for the Rhodes grass alone). A small proportion of legume in the pasture both increases the amount of N available to the associated grass and increases the level of protein in the diet (Mott, 1981). The addition of as little as 10% of legume (DM basis) in the diet or forage system may lead to large increases in forage intake and animal performance (Minson, 1980). In this study the proportion of legume in the mixture averaged about 20% throughout the period of the trial.

Table 3. Average daily liveweight gains, total gains/ha and number of grazing days/season on Rhodes grass and Rhodes grass-Silverleaf desmodium pastures, 1982/83 to 1984/85.

	1982/83			1983/84			1984/85		
	Average daily gain (kg)	Total gain (kg/ha)	Grazing days	Average daily gain (kg)	Total gain (kg/ha)	Grazing days	Average daily gain (kg)	Total gain (kg/ha)	Grazing days
Rhodes grass	0.49a	662	1340	0.70	527	1177	0.62a	521	1218
Rhodes grass plus Silverleaf desmodium	0.62b	669	1184	0.70	526	1165	0.70b	560	1195

Figures within a column followed by different letters differ significantly (P<0.05).

It would appear that the better performance of the animals on the grass-legume pasture was related to the higher CP content of the forage. There were strong positive correlations between daily liveweight gain from January to May and the CP content of the forages in both the pure grass pasture ($r^2 = 0.80$) and the grass-legume mixture ($r^2 = 0.89$).

CONCLUSIONS

The unfertilized grass-legume pasture gave similar forage dry-matter yields to the pure stand of Rhodes grass, which received 40 kg N/ha. In addition, the CP content of the mixed forage was higher than that of the grass alone, which resulted in significantly higher average daily liveweight gains from the grass-legume pasture in two of the three seasons of the trial.

Thus, it would appear that for smallholder cattle fattening systems in Malawi, the inclusion of a legume component in pastures could eliminate the need for expensive N fertilizers without reducing animal performance.

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FORAGE LEGUMES IN THE CATTLE DEVELOPMENT AREA PROGRAMME OF ZAMBIA

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ABSTRACT

The Zambian Cattle Development Area (CDA) Programme was conceived to promote smallholder cattle production on a regional basis within Zambia. In future, major emphasis will be placed on integrating cattle and crop production and on adaptive research. A serious constraint on the development of smallholder cattle production is the fact that traditional land tenure systems in Zambia do not allocate land for grazing.

Experiments with forage legumes on the Mwase CDA have clearly indicated the potential of growing maize in a live mulch of forage legumes. However, further testing is needed in order to establish whether such a system can be recommended to farmers on the basis of advantages to crop production alone, since, under the current system of communal grazing, individual farmers will not benefit from producing more or better forage.

FORAGE NETWORKS

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ABSTRACT

The characteristics of networks are described, their advantages discussed, and the organisation and objectives of several forage networks are presented. Two African networks, the Forage Network in Ethiopia and the Pasture Network for Eastern and Southern Africa are examined in some detail. Factors critical to the degree of success of a network formed to develop forage production include the character of the co-ordinator, the network newsletter and the breadth of membership and programme.

INTRODUCTION

Networks can be defined as associations of individuals with common interests. They can be large, involving hundreds of individuals, or small, with 10 or less, formally organised or casual, with the participants contacting each other as needed or desired. Membership may be open to all with similar interests or exclusive, confined to those meeting specific, defined criteria. These characteristics are normally determined by the needs and philosophy of the members, organisers and funding agency.

Associations of individuals with common concerns are not new, but the term network has become popular recently. Plucknet and Smith (1984) trace the beginnings of agricultural networks to colonial research stations, which were organised in international networks within the holdings of each imperial power, but tended to be exclusive with regard to other colonial powers. In the United States the first formal agricultural networks appeared in the 1920s and the first multinational germplasm screening trial in the 1950s, with the International Stem Rust Nursery. This network involved 150 researchers in 40 countries in testing wheat germplasm for resistance to wheat stem rust. International agricultural networks have since become very popular and there are now more than 100 (Plucknet and Smith, 1984).

The stimulus for starting agricultural network activities can usually be attributed to some combination of the agriculturalists or national agencies who will form the membership, a funding agency, and an International Agricultural Research Centre (IARC) such as ILCA or CIAT.

Some funding agencies have been particularly active in promoting networks; the International Development Research Centre of Canada (IDRC), for example, in its first 9 years spent 51% of its Agriculture, Food and Nutrition Programme budget on network projects (Nestel et al, 1980). IARCs have a considerable involvement in networks and they have made a substantial contribution to the initiation and development of larger, international networks, particularly in the field of germplasm screening.

Although the organisation of networks varies greatly, certain features are common (e.g. IDRC networks; Nestel et al, 1980): participants (a few to several hundred), mechanisms to link the participants (commonly a coordinator), advisory committees, outside consultants, training programmes, workshops and publications.

Networks are valuable mechanisms for efficient enhancement of research capabilities. They create links between those with common interests and thus encourage the dissemination of information and germplasm and the formation of groups of scientists in order to solve problems effectively. New ideas are introduced by formal and informal training given by consultants and by peer groups within the network; they also create opportunities for critical examination of work programmes of individuals and institutions and the development of global professional contacts, leadership, and trial designs and local philosophies suited to local conditions. Coordination of research is encouraged, reducing duplication, and the value of trials, particularly screening trials, is enhanced by multilocation testing.

Networks are attractive to funding agencies and to IARCs as research and development tools, due to their cost-effective use of established personnel and institutions and their flexibility in being readily started, altered or terminated, as they usually require little in the way of formal agreements.

Networks are attractive to scientists and institutions as they break the professional isolation that is common in the Third World. They provide opportunities for travel internationally to workshops, training courses and to visit other researchers. Networks can provide internationally recognised consultants to advise on research programmes, and this support, plus the availability of new germplasm and the development of standard and multilocation trials within the network, assures the scientist and his supervisors that he is doing important work of internationally recognised quality. The status of the researchers is thus boosted. There are opportunities for leadership, for rapid publication and for presentation of work and philosophies of the members in the forum of interested peers.

A review of IDRC research networks (Nestel et al, 1980) listed a number of factors for success. The goals of the network should be broad and include known resource development, production of research results and the provision of information for planners and development workers. The network should be flexible, changing to meet new needs. A regional, rather than continental, emphasis is more meaningful to participants. Consultants should have continuity and be as widely used in the network as possible, for they, along with workshops and newsletters, are very important in the development of a common philosophy and links within the network. Links should be developed with IARCs and institutions in developed countries. There should be a network coordinator for day-to-day management and an advisory committee of members or consultants to advise the leadership.

Plucknet and Smith (1984) listed factors important for the success of IARC-based networks, particularly those based on international nurseries. They contend that such networks should be based on a widely shared problem that is clearly defined by the network, the solution to which is sought using a realistic research agenda. They should have strong and effective leadership. The self-interest of potential participants should be appealed to such that those with sufficient training and expertise to contribute will participate and be willing to commit resources. Outside funding is necessary in order that the acquisition of foreign exchange is not a problem.

As can be seen from the two lists of criteria, the IDRC networks and goals are much more general and open than those of the IARC nursery networks, which are essentially exclusive and have narrowly-defined research agenda and goals. The IARC nursery networks commonly concern a single crop and may emphasise one aspect of the crop. The International Rice Research Institute (IRRI), for example, has separate networks for genetic testing, agronomy, cropping systems, soil fertility and fertilizer efficiency, and farm machinery development (IRRI, 1982).

FORAGE NETWORKS

The Australian-South East Asian and Pacific Forage Research Network

This network was started in 1984 (Evans 1984) with the appointment of an Australian coordinator, and is funded by the Australian Centre for International Agricultural Research (ACIAR) and the Australian Development Assistance Bureau (ADAB). It was started in response to increased interest in pastures and forage production in the region, aroused by reports of successful research on pastures in tropical areas of Australia and through bilateral and multilateral forage research projects.

The aims of the project are to increase the effectiveness of research in the region by providing support and encouragement in research and to help overcome communication problems. Specific goals are to (i) improve research planning, (ii) encourage research in areas of mutual interest to participants, (iii) strengthen technological capacity at all levels, (iv) strengthen each country's information base, (v) help to provide extension of research developments, and (vi) to develop a network base for long-term contacts.

A primary network has been formed of 10 leading scientists (core members) active in research, based at institutions involved in significant forage research and at which the quality of staff and research are at a level to benefit from and contribute to network activities. Five countries in the region have such a capacity.

The network is thus, at present, exclusive, with well-defined institutional and individual membership criteria but broad research goals. Its impact so far seems to be very limited.

The CIAT International Tropical Pastures Network (RIEPT)

The Tropical Pasture Programme of CIAT, with funding from IDRC, has acted as a catalyst with national research institutions in the formation of RIEPT for its area of research emphasis, the tropical forests and savannas on acid, infertile soils (Toledo, 1982; Toledo et al, 1984).

The objectives of RIEPT are to:

1. Study the range of adaptation of forage grass and legume germplasm in low altitude tropical ecosystems,
2. Encourage the testing of promising germplasm in pastures at research institutions in the region, and to

3. Promote technical development in pasture production in the regions of expanding livestock production in tropical America and to assist in the exchange of scientific information and research methodologies.

So far, the network is based on a progression of germplasm screening trials; the most promising lines in early trials are subjected to more intensive testing in later trials:

Series A Evaluation of the survival of a large number of entries (100-150) in a few highly representative sites in a major ecosystem.

B Determination of the dry-matter productivity of 20 to 30 lines from CIAT and national programmes in as many sites as possible.

C Evaluation of about 10 lines in small mixed grass-legume plots under grazing.

D Measurement of pasture productivity and persistence in terms of animal products.

E On-farm evaluation of improved pastures.

The network was started in 1979 when the first organisational meeting was held and a CIAT coordinator was hired. Work has reached series C trials and series D trials are being established. The network has biennial meetings, at which participants present their network research results, and workshops, which are usually held at the same time as the network meetings.

RIEPT thus follows the common pattern of IARC networks in being rather narrow in scope, limited to researchers who participate in network trials, and being rather heavily dependent on the IARC.

International/Regional Working Groups on Natural Grazing Resources

The Grasslands and Pasture Crops Group of FAO has been involved in international networks since 1977 (F Riveros, personal communication). It has started two networks in South America, and one each in the Caribbean and Mediterranean regions, the Himalayan highlands and Malaysia. Another network is planned for the highlands of the Andes.

The objective of these networks is to encourage better forage research by linking researchers working in similar environments. The two South American networks, for example, link researchers in several countries into separate networks for the Chacos and Campos environments.

The networks have such activities as annual meetings/ workshops, group monitoring, training and coordinated research. A wide range of research activities are undertaken to solve local environmental problems: biological N fixation, dynamics in natural grasslands, ecological surveys, large-scale grazing trials, control of weed grasses.

While FAO plays an important role in guiding the networks, each network has its own part-time secretariat composed of a senior researcher/administrator and a secretary, and each country has its own part-time national coordinator for each network in which it is involved. FAO provides funds for these coordinating activities, for the annual meetings/workshops, small research equipment, operating funds, training, consultants etc.

While narrow in the sense of concentrating on researchers and on individual environments, these networks are flexible and broad in terms of the research activities undertaken and apparently have a substantial impact on research for small financial inputs.

The Forage Network in Ethiopia (FNE)

Before the FNE was formed there was little forage research in Ethiopia, due partly to an emphasis on food crops, and partly to a lack of trained personnel. Individual government ministries and research and development organisations worked in almost complete isolation. Ill-conceived and poorly planned work was not uncommon, a narrow range of germplasm was available for testing, results were based on screening at a limited number of sites, efforts were duplicated, and results were not publicised.

The FNE was organised to promote forage production. It aims to achieve this by increasing communication between those interested in forages at all levels, and by encouraging testing, seed production and extension of promising forage germplasm.

Formed in October 1980 by forage researchers from ILCA and three government organisations (the Ministry of Agriculture, the Institute of Agricultural Research and the Arsi Rural Development Project), its activities were based initially on participation in multilocation trials. It has since grown to include participants from a wide range of Ethiopian Government and non-government organisations, including aid and development groups, colleges, the Alemaya University, workers from other fields of research and development and farmers. Researchers in Djibouti have recently joined the Network.

Network activities are planned by a steering committee composed of elected officers and representatives of all the participating groups. Only those committee members based near Addis Ababa manage to attend the meetings, but the views of the other committee members are sought whenever possible.

The annual general meeting is one of the most important network activities. At this meeting officers are elected, research results of attending organisations and FNE multi-locational trials are presented, new trials for the coming season are discussed, and talks are given on various forage-related topics.

Another regular activity is the annual field trip which provides the opportunity for members to view each others work and to visit development projects.

The FNE Newsletter has proved to be very popular. Published four times a year it contains the minutes of FNE meetings, local and FNE forage news, news of other networks and meetings, designs and results of FNE multilocation trials, activities of FNE members and advisory notes on the production and utilisation of forage species. The newsletter has created a great deal of interest in the FNE, both in Ethiopia and abroad, and has a wide readership, from ministers to extension workers and farmers. It has done much to create a positive attitude toward the network in government circles, to encourage better coordination of research efforts, and to provide a local medium for publication of ideas and results.

The multilocation trials organised by the network are very popular and form a system of screening not dissimilar to that used by CIAT's pasture network. The levels of screening to date are:

1. Natural grassland inventory (including DM production estimates).
2. Initial adaptation trials. These are mainly strip trials in which rainfed or irrigated grasses, legumes and browse are planted in unreplicated strips, normally under two fertilizer rates, zero and minimal P (and N for grasses). Detailed observational data are taken, and the strips may be cut or grazed once established. Legume and browse trials are usually planted in natural or sown pastures.
3. Replicated yield trials, pure sward.
4. Replicated yield trials, mixed sward.

There is a wide range of environments and farming systems in Ethiopia, and thus network trials have to be more flexible than those in the CIAT network. Species are chosen for specific environments and farming systems. The work so far has delineated a number of major forage environments (Table 1), using altitude as the primary consideration,

Table 1. Some major forage environments in Ethiopia.

Altitude	Soils
2600 +	Alfisols, Vertisols
2000 - 2600	Alfisols, Vertisols
1000 - 2000	Alfisols, Inceptisols, Ultisols
0 - 1000	Alfisols, Vertisols, Ultisols

followed by soil type (mainly drainage and pH) and then rainfall and farming system. There are a large number of forage environments, as most altitude environments have rainfall regimes ranging from humid to semi-arid and there is considerable variation in local farming systems, which have management systems ranging from nil in communal grazing lands to high in such systems as intercropping and reserved fodder. The degree of management is usually related to population density and the importance of livestock in the area. The results of the first series of multilocation trials have been analysed and published in the FNE Newsletter.

The individual ministries and organisations meet the travel costs and per-diems for their staff attending the FNE meetings and field trips, and the expenses of the multi-location trials that they undertake. ILCA provides transport for the field trips, germplasm, computer facilities, and publishes and distributes the FNE Newsletter.

The network has done much to stimulate and coordinate forage research in the area both within the network and as cooperative research between institutions, with only very small financial inputs. ILCA, for example, has cooperative seed production and research programmes with the Ministry of State Farms, Horticulture Development Corporation, at one site, and the Ministry of Agriculture at two sites. These sites are also used for FNE demonstrations and training.

The FNE is thus similar to IDRC networks in being broad in its goals and membership. These factors have contributed much to the network's success.

The Pasture Network for Eastern and Southern Africa (PANESA)

PANESA started at the instigation of IDRC. The original members were the participants in a regional workshop held in Zimbabwe in October 1984, at which 14 countries in eastern and southern Africa were represented.

The aim of the network is "to improve effectiveness in pasture research in participating countries and to expedite the application of improved technology by farmers and grazers at all levels of management (extensive, semi-intensive and intensive). In this context, pasture is defined as encompassing natural pasture, planted grasses, legumes, browse and fodder (including crop residues)" (PANESA, 1984). The objectives of the network are thus much broader than those of the networks described earlier in this paper. The detailed objectives are to:

1. Develop national capacities in planning and management of practical pasture research and development programmes,
2. Expedite utilisation of research developments,
3. Strengthen technological capacity through training and improved communication,
4. Provide a means for introduction and exchange of germplasm,
5. Encourage communication among farmers and extension and research personnel,
6. Encourage participating countries to undertake coordinated research programmes of practical application in areas of mutual interest,
7. Cooperate with other organisations interested in pasture research both within and outside the region, and to
8. Assist in allocating external funds for pasture research and development programmes in the region.

Membership is open to all of those interested in pastures and forages, including farmers and extension and research workers.

PANESA is managed by a working committee consisting of a chairman and four members elected at an annual general meeting/workshop by representatives of national and sub-regional networks. Representatives of technical and financial supporting agencies can be coopted onto the working committee. The network coordinator is also a member.

The annual general meeting reviews the progress of the network and elects and provides guidance to the officers and coordinator on the coming year's programme and its implementation.

An important feature of the organisation of PANESA is that it encourages autonomous national and sub-regional networks. These networks are able to mobilise interest to carry out network activities of local concern. Two such networks already in existence are the Zimbabwe Grasslands Society and the Forage Network in Ethiopia. The formation of PANESA has initiated activity in other countries, as a result of which the Forage Network of Kenya (FNK) and the Tanzanian Forage Resources Network were formed in 1985 and other networks are being organised in Botswana and Malawi. Countries that have few researchers and similar forage interests are encouraged to form subregional networks.

PANESA activities to date have included three working committee meetings, held in Zimbabwe, Nairobi and Addis Ababa. These meetings organised the network, prepared a funding proposal, held discussions on the possible role of ILCA and its programmes in supporting the network, and planned a newsletter, training course (on forage plant introduction and initial evaluation) and the 1986 workshop and general meeting. The 1986 workshop will be held in Nairobi, 11-16 November and will be on the topic "Feed Resources for Small-scale Livestock Producers".

IDRC will provide funding to ILCA to cover part of the costs of PANESA, initially for 2 years. This will provide PANESA with support for a coordinator, a typist, a vehicle and office expenses. The coordinator will be an ILCA staff member, based at ILCA Headquarters in Addis Ababa and will be selected by ILCA, IDRC and the Working Committee. ILCA will provide support for the network in the form of two short training courses, ILCA staff as consultants, germplasm and computing and training facilities.

USAID has also expressed interest in supporting pasture networks in Africa. Areas in which further funding is required include research activities, seed production, training (both short, locally-based courses and longer term training at universities and colleges overseas), national networks, including travel and greater newsletter support, and group monitoring.

PANESA is thus another network which is broad in its goals and membership.

CRITICAL FACTORS FOR SUCCESS

Three factors may be critical to the success of a network dedicated to the improvement of forage production: the character of the coordinator, a newsletter and the degree of openness of the network.

1. Coordination may be done by a committee or by an individual. Commonly one person has the day-to-day responsibility for leading network activities and a committee provides general guidance. The success of a network is thus largely dependent on the coordinator. His enthusiasm, character, experience and attitudes are of great importance. Some important characteristics of a coordinator are listed below; the absence of any one of these can markedly affect the success of a network.

   - sufficient time and enthusiasm
   - open, friendly, flexible, tactful, mature, socially inclined
   - must not be out to make his scientific reputation

- keen to advance the careers of others, and to encourage the development of local leadership
- be able to provide tactful, indirect leadership
- flexible and unbiased in his/her scientific outlook. Must not have particular philosophies, trial designs or plants which he feels are superior and will promote to the exclusion of others
- broadly experienced in both research and developing countries so as to know what is feasible and what is of importance
- organised, answers correspondence promptly and meets deadlines, able to run an office
- able to write, newsletters will depend on him
- prepared to spend a great deal of time travelling
- not be tight with money as his social costs will be higher than his per-diems.

2. A newsletter is an important part of a network. Published regularly it creates links between members of the network as well as with outsiders. It should be of reasonable quality and even if simply produced have an interesting mixture of opinions, news and scientific articles written by members and others. It should be widely distributed, going not only to network members, but to their supervisors, to those who are potential members and to those with an interest in the subject. Wide distribution will allow non-members to keep up with developments and to gain from the experiences of the network. The newsletter will do much to create a favourable impression of the network with administrators and funding agencies.

3. A forage network that has broad goals, a flexible approach and open membership will be more successful than one that is narrow in its goals and exclusive in membership. The narrower philosophy is exemplified in many of the IARC networks, which are often uni-crop, uni-trial and whose membership involves only those who are

participating. Undoubtedly such networks suit some crops and situations where farming systems are uniform in extensive environmental zones. They are probably easier to manage and fund, and may achieve results more rapidly due to their concentration of effort. However it is difficult to envision how, certainly in the context of sub-Saharan Africa, a uni-crop, limited membership network could have any impact on forage production in the multiplicity of environments and farming systems. It is apparent that a much broader concept is required, with stimulation of work in many fields and environments at the same time, e.g. cut-and-carry, fodder banks, grazing etc. While regional interests and major environmental zones must be recognised, the creation of separate networks for separate areas of work and environments would be disadvantageous.

A wide membership is advantageous; limited membership can create apathy or negative attitudes on the part of those excluded and limit the enthusiasm, exchange of ideas and flow of information. Ideally all those interested in forage should be involved and feel responsible for, and part of, the network even if they are not active members. Administrators, researchers, extension agents and farmers should all be involved in the production and exchange of information. Those who are not directly involved in forages but who have an interest, should be encouraged to participate also. The advantages of the involvement of those involved with soils research and conservation, pulse crops, forestry, development projects and planning is obvious.

Networks are thus valuable tools that can assist in the development of forage production in Africa. They are currently being formed in many countries in East and southern Africa and ILCA will shortly begin work on initiating networks in West Africa. The experiences of networks already in existence should be carefully examined to guide the development of new ones.

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SYNTHESIS AND RECOMMENDATIONS

SYNTHESIS AND RECOMMENDATIONS

Synthesis statements and recommendations were prepared by two working groups (one for each session) and refined in discussion during the concluding session.

The recommendations were made for consideration by national research institutes as well as by ILCA. They reflect a consensus on the suggestions emerging from individual presentations.

Nutrient and water constraints to forage legume growth

* Nutrient and water constraints are related to the specific requirements of particular legumes.
* If a forage legume is grown in combination with food crops, water and nutrient management are basically dictated by the requirements of the food crops. Low nutrient requirements of legumes help reduce the need for fertilizer inputs.
* Even though there are large differences among sub-Saharan farming systems in terms of access to fertilizers, nutrient management practices will have to work with generally low levels of inputs.
* Both forage legumes and their associated rhizobia are affected by nutrient and water constraints. Determining their relative responses to these constraints requires adequate measuring techniques.

Recommendations

1. Phosphorus

* Studies of the efficiency of use of P in farming systems, with special reference to residual P in crop rotations.
* Studies of the use of alternative P sources in relation to costs and efficiencies.
* Selection of cultivars adapted to low available P and possibly use of mycorrhizae.

* Determination of appropriate points of P fertilizer interventions in cropping systems.
* Strengthening of soil testing facilities as a means of predicting response to P fertilization.
* Studies of interactions between P, soil and crop species/cultivar for optimisation of P inputs.
* Determination of the P status of forage legumes.

2. Other elements

* Studies of the differential requirements among species and cultivars.
* Survey of the distribution of various nutrient-deficient soils, and their description.

3. Water

* Studies of the relative water-use efficiency of legumes.
* Studies of management of soils and crops to improve water-use efficiency.
* Selection of cultivars that tolerate or escape drought.
* Measurement of soil/water relations.

4. Biological nitrogen fixation (BNF)

* Studies of BNF measurement techniques.
* Selection and production of adapted rhizobia.
* Determination of N budgets for cropping systems.
* Determination of the fate of biologically fixed N.

Forage legumes in production systems

Forage legumes fix a larger proportion of the N they need for growth than do most grain legumes, and are therefore more effective in restoring soil fertility.

In subsistence cropping systems legumes are the most important source of N, since little fertilizer is used. The use of forage legumes in both pasture and food crop production systems is essential in order to promote food security in subsistence farming systems. Forage legumes, including leguminous shrubs and trees, provide generally high-quality feed that can be used to supplement crop residues, which are the main source of animal feed in many smallholder farming systems.

The ability of forage legumes to provide high-quality feed and to increase soil fertility makes them central to the exploitation of the complementarities between livestock and crop enterprises. Much of the potential of many African farming systems lies in these synergies.

Recommendations

1. Legume feed production systems

1.1. Intercropping forage legumes with food crops

* Selection of legume species and cultivars and food crops in order to match growth patterns and architecture of partners for optimum resource utilisation.
* Studies on how to minimise competition between species in intercropping systems.
* Use of simulation models in the development of intercropping systems.
* Determination of the fate of N in intercropping systems (especially with reference to long-term transfer patterns).
* Economic evaluation of intercropping systems with emphasis on long-term effects and with reference to other systems of legume use.

1.2. Ley farming (rotation of cereals and forage legumes)

* Correct identification of forage legume species and cultivars.
* Studies of the constraints on and the scope for the introduction of ley-farming in different farming systems.

* Emphasis on long-term soil fertility management for sustained crop production.
* Determination of the fate of N under ley systems.
* Studies of the contribution of ley-farming to soil and water conservation.

1.3. Alley farming, fodder banks

* Economic assessment.
* Studies of long-term effects (agronomy, nutrients, tree survival and (re)establishment, management.
* Germplasm selection, priority ranking in selection criteria according to regional setting.
* Germplasm selection for dry and for cool ecosystems and for problem soils.
* Maximisation of animal utilisation of alley offtake.

2. **Research approaches and priority areas**

* On-farm research and effective research-extension links on farmers' fields are necessary for effective development of forage legume technologies.
* Successful development of forage legume technologies requires the early involvement of the animal in the evaluation process.
* Forage or shrub legumes should be used as supplements to diets based on crop residues (N supplementation).
* More research is needed into establishment of forage legumes in a variety of systems (legume-based pastures, legume leys, intercrops, sole crops, alley crops, protein banks, rangelands improvement).
* Application of successful legume technologies will not be feasible without an effective legume seed production programme.
* Existing information on forage legumes needs to be compiled in order to contribute to more rapid progress in technology generation.

APPENDIX I

PARTICIPANTS AND OBSERVERS

Workshop on

"Potentials of forage legumes in farming systems of sub-Saharan Africa"

16–19 September 1985

International Livestock Centre for Africa (ILCA), P.O.Box 5689, Addis Ababa, Ethiopia

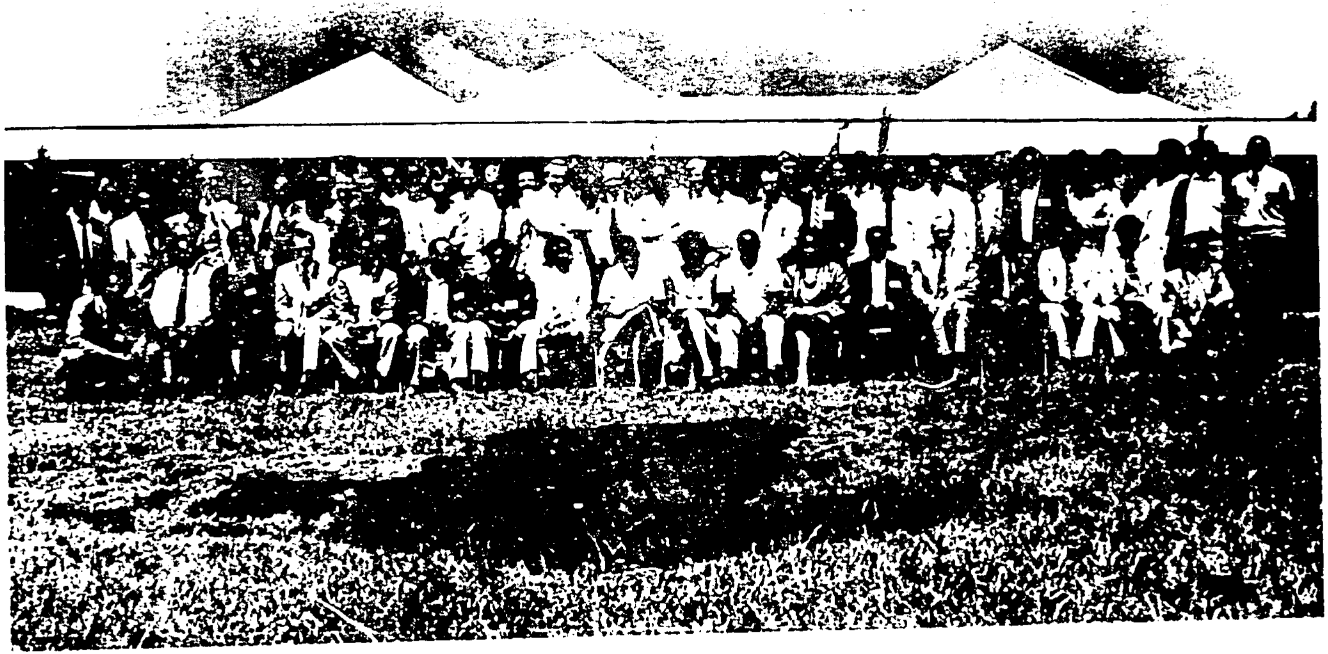

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Figure X: Environmental zones of sub Saharan Africa