Forage legumes in African crop–livestock production systems*

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SUMMARY

THE POTENTIAL *of forage legumes to increase the productivity of crop–livestock systems has been studied by ILCA under different ecological and management conditions. In the Ethiopian highlands, species within the* Vicia, Trifolium *and* Medicago *genera show promise. Among these the* Vicia *genus stands out with its relatively high dry-matter yields, high N content, and consistently high residual effects which make it very attractive for intercropping. In the subhumid zone of West Africa,* Stylosanthes *species show good potential, especially if the danger from anthracnose can be eliminated. Of the various legume–cereal technologies tested, the cut-and-carry method, intercropping, sequential cropping and alley farming are most likely to be adopted by farmers in sub-Saharan Africa.*

INTRODUCTION

During the past decade, the escalating cost of N fertilizers has fostered research on biological nitrogen fixation (BNF). Several universities and international research centres (e.g. MIRCEN, CIAT and IITA) became actively involved in BNF research. However, it is now widely recognised that much of this work has little value for developing countries (Kokke, 1984), because it does not solve local problems of low soil fertility, low and erratic rainfall, high solar radiation, and scarce fertilizers.

The origins of the BNF technology can be traced to efforts to improve the meat industry in New Zealand, and to increase wheat production in southern Australia where rainfall and fertilizer response are highly uncertain. The clover/wheat technology has been transferred with reasonable success to the Mediterranean region of North Africa, which is traditionally a wheat/fallow region (Bakhtri, 1977). The change was fairly easy: the farmer only needed to substitute a self-regenerating legume for the fallow period. Decreased soil erosion and higher soil fertility led to higher wheat yields, more feed, and more sheep.

This paper examines ILCA's research on forage legumes in the past few years. The potential role of forage legumes in increasing crop–livestock productivity in sub-Saharan Africa is discussed, and priorities for future research are outlined.

FORAGE LEGUMES IN AFRICAN FARMING SYSTEMS

In most of sub-Saharan Africa, farming systems are predominantly small-scale and have both crop and livestock components. Introducing forage legumes into such systems will improve soil fertility, crop yields, and herbage quality, and make the system more sustainable.

Rotations

Ley farming

Cereal crops are grown in rotation with forage legumes under ley farming. The technique was developed in southern Australia, and its advantages have been summarised by Webber et al (1977).

Ley farming has been advocated for the West African savanna (Jones and Wild, 1975), but so far attempts to introduce it in the region have met with little success—probably because there are few adapted annual legume cultivars capable of producing large amounts of seed.

Cut and carry

The system has been studied at ILCA's headquarters in Shola and at its research station in Debre Zeit, both in the central highlands of Ethiopia. Results show that vetch, lablab and some clovers are capable of leaving 30–60 kg N ha^{-1} in the top 20 cm of the soil profile through their root systems (L. A. Nnadi and I. Haque, ILCA, Addis Ababa, Ethiopia, unpublished data). Although these amounts will not give maximum cereal yields, they are sufficient to meet the N requirements of cereal crops grown in subsistence systems.

Table 1 shows the effect of previous cropping on sorghum and maize grain yields on a soil with vertic properties. In 1985, the yield of sorghum after *Trifolium steudneri* was double that after oats*(Avena sativa),* while in 1986 vetch *(Vicia dasycarpa)* increased maize yield twofold compared with the control.

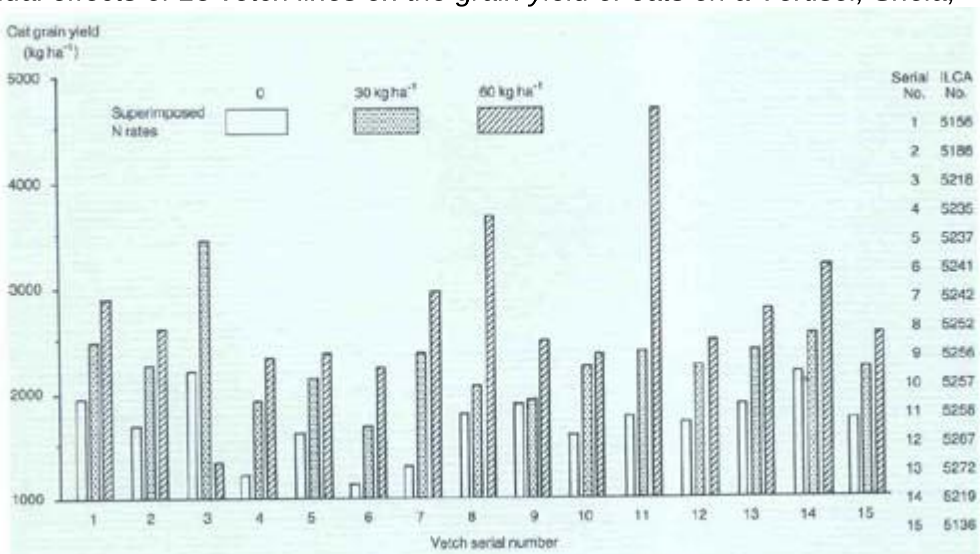
Table 1. *Effect of preceding crops on grain yields of sorghum and maize on a soil with vertic properties, Debre Zeit, Ethiopia, 1985/86.*

1984 crop	1985 sorghum yield (kg ha^{-1})	1986 maize yield (kg ha^{-1})
Trifolium steudneri	2632.0a[1]	2730.7ab[1]
Vicia dasycarpa	2130.3ab	3273.7a
Lablab purpureus	1549.7b	2461.7b
Trifolium tembense	1842.0ab	2170.7b
Avena sativa	1386.0b	1571.3c

[1] Within columns, values followed by the same letter are not significantly different at the 5% level (Duncan's Multiple Range Test).
Source: I. Haque (ILCA, Addis Ababa, Ethiopia, unpublished data).

The residual effects of 15 vetch lines on the grain yield of oats on a Vertisol were investigated at Shola in the 1983/84 cropping season. The results show that lines no. 3 (ILCA accession no. 5218) and 14 (ILCA accession no. 5219) benefit a subsequent oats crop: in both cases the cereal yielded grain at more than 2000 kg ha^{-1}, indicating the potential contribution of the legume to soil fertility (Figure 1).

Figure 1. *Residual effects of 15 vetch lines on the grain yield of oats on a Vertisol, Shola, Ethiopia, 1984.*

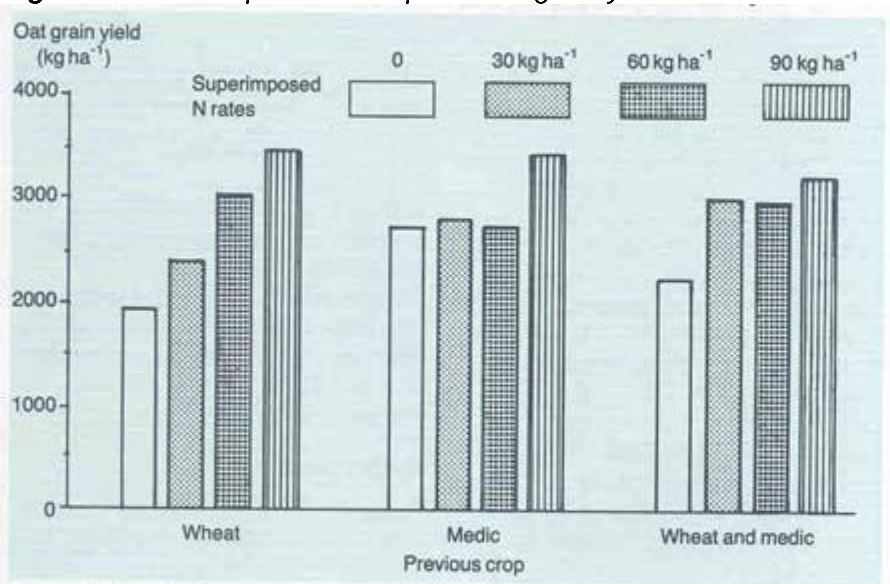


Source: I. Haque (ILCA Addis Ababa, Ethiopia, unpublished data)

A similar study was conducted in 1984/85 with 27 clover accessions. There was a considerable range in both dry-matter (DM) and grain yields of oats following the various clover lines, but on about 50% of the plots previously under clover, grain yield was over 3 t ha^{-1}. However, because there was no control, it is difficult to determine what proportion of this was due to the legume. Oat grain yields following trifolium accessions nos. 9435, 9956 and 10181 were over 3.3 t ha^{-1}, and deserve further investigation (I. Haque, ILCA, Addis Ababa, Ethiopia, unpublished data).

In another trial at Shola the grain yield of oats following *Medicago truncatula* cv Jemalong was higher than that of oats following pure wheat or a wheat/medic mixture (Figure 2). In a study at Debre Zeit, the grain yield of wheat crop grown on Vertisol broadbeds increased when it followed forage legumes. However, the results were not significant compared with the control oats (Table 2), which might be due to a higher initial amount of available N.

Figure 2. *Effect of previous crops on the grain yield of oats on a Vertisol, Shola, Ethiopia, 1984.*



Source: I. Haque (ILCA, Addis Ababa, Ethiopia, unpublished data).

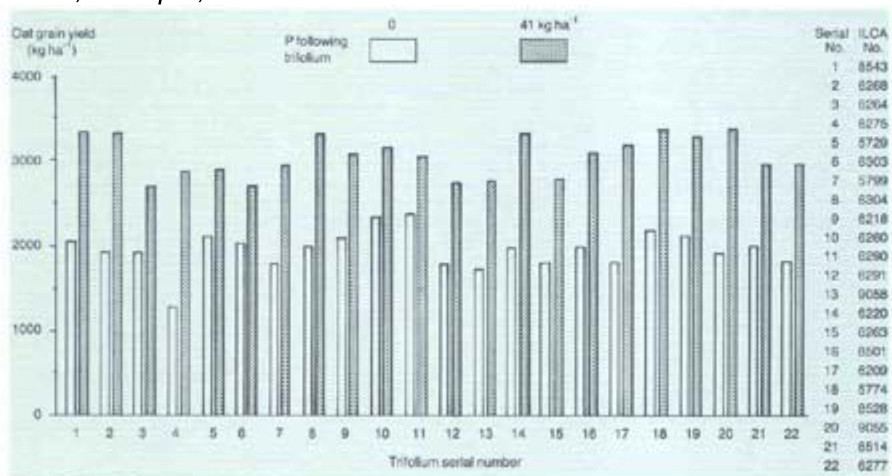
Table 2. *Effect of previous cropping on wheat grain yields on a Vertisol, Debre Zeit, Ethiopia, 1986.*

1985 crop	Wheat yield[a] (kg ha^{-1})
Medicago polymorpha	2034.3
Vicia dasycarpa	1689.3
Lablab purpureus	1685.3
Trifolium steudneri	1427.0
Avena sativa	1357.3

[a] Because of high coefficients of variation, the differences in wheat yields after the forage legumes and the control *(Avena sativa)* were not significant.
Source: I. Haque (ILCA Addis Ababa, Ethiopia, unpublished data).

The effect of P fertilization on BNF was studied on a Vertisol at Shola in 1983/84. Following 22 trifolium accessions, oats were planted in plots that had received P at either 0 or 41 kg ha^{-1} as TSP. The increase in the grain yield of oats over the control (legume without P) varied from 28.2 to 100.2% (Figure 3). Different trifolium accessions contributed different amounts of N to the following oats crop, but the effects of the legume and P were confounded. Nevertheless, the results show the importance of P application for BNF and, consequently, for increasing cereal grain yields on Vertisols.

Figure 3. *Residual effects of trifolium and phosphorus on the grain yield of oats on a Vertisol, Shola, Ethiopia, 1984.*



Source: I. Haque (ILCA, Addis Ababa, Ethiopia, unpublished data).

In a trial on an upland soil at Debre Zeit, DM yields of wheat following forage legumes were significantly higher than that after oats (Table 3). A similar trend was observed in grain yields.

Table 3. *Effect of previous cropping on dry-matter (DM) and grain yields of wheat on an upland soil, Debre Zeit, Ethiopia, 1986.*

1985 crop	Wheat	
	DM yield (kg ha^{-1})	Grain yield (kg ha^{-1})
Vicia dasycarpa	4015.7a[1]	2612.0a[1]
Trifolium steudneri	3543.0ab	2599.5a
Medicago polymorpha	3443.2ab	2531.2a
Fallow	2745.7bc	2090.2ab
Avena sativa	2320.5c	1752.7b

[1] Within columns, values followed by the same letter are not significantly different at the 5% level (Duncan's Multiple Range Test).
Source: I. Haque (ILCA, Addis Ababa, Ethiopia, unpublished data).

Fodder banks

Fodder banks are dense stands of forage legumes grown on a small area (about 4 ha) for 2 to 3 years to provide dry-season feed supplementation. Research by ILCA has so far been restricted to the subhumid zone of Nigeria and to *Stylosanthes guianensis* cv Schofield, *S. guianensis* cv Cook and *S. hamata* cv Verano.

After a few years, fodder banks usually become infested with nitrophilous grasses. The area must therefore be planted to a cereal crop, and the system becomes a type of rotation. Because small livestock holders are interested in the production of some grain in addition to animal feed

(FAO, 1983), crops could be grown in rotation in fodder banks. This would provide valuable crop residues in addition to leguminous feed.

Mohamed-Saleem (1986a) reported that growing forage legumes in fodder banks decreases soil bulk density and increases subsequent maize yield. Soils that had been under *S. hamata* for 3 years and *S. guianensis* for 2 years gave maize yields equivalent to yields obtainable with 90 and 110 kg N ha^{-1} respectively (Mohamed-Saleem, 1986b). There were problems of bush fire which, together with fencing, need attention if fodder banks are to be successfully adopted in the subhumid zone of Nigeria.

Dual-purpose legumes

Reports of the highly beneficial effects of grain legumes on soil N and the grain yield of subsequent cereals are numerous (Jones, 1974; Narwal et al, 1983; De et al, 1983; Kumar Rao et al, 1983). Where farmers are reluctant to invest in forage legumes, forage-type grain legumes could be used if their DM yields are sufficiently high. ILCA's work in Mali showed that by introducing cowpea into the crop rotation, millet grain yields increased by 60% compared with yields of a first-year millet crop (ILCA, 1984).

Alley farming

Alley farming is an agroforestry system where arable crops are grown between hedgerows of legume shrubs. The hedgerows are pruned periodically during the cropping phase to provide green manure, additional fodder for animals, staking material, and to prevent shading of the arable crop. Forage legumes suitable for alley cropping are mostly in the *Albizia, Calliandra, Cassia, Inga, Leucaena, Gliricidia* and *Sesbania* genera (Mulonguy and Kang, 1986) .

There is a conflict in the utilisation of the hedgerow prunings for soil improvement and for animal feed, especially before soil fertility increases. In general, however, livestock can make use of most of the prunings if manure is returned to the soil to maintain its fertility.

In a first trial at Debre Zeit, *Sesbania sesban* planted in 4-m wide alleys (10% slope) yielded DM at 800 kg ha^{-1} annually (S. Jutzi, ILCA, Addis Ababa, Ethiopia, unpublished data). In addition to the green matter (4% N) for mulching and animal feed, considerable amounts of fuelwood could be harvested. The contribution of the system to soil fertility, erosion control, and sustainable crop production was examined by Jutzi et al (1987).

Nitrogen contribution. Investigations by ILCA and IITA of the contribution of alley farming to soil N have been encouraging: Mulonguy and Kang (1986) reported N at 140 and 230 kg ha^{-1} $year^{-1}$ respectively for leucaena and gliricidia planted in hedgerows 4 m apart. ILCA's work at Ibadan, Nigeria, shows that N derived from leucaena prunings averaged 165 kg ha^{-1} over a 3-year period (A. Atta-Krah, ILCA, Ibadan, Nigeria, unpublished data).

Other nutrients. In a recent trial on an Alfisol in southern Nigeria, leucaena prunings contributed 11 kg P, 153 kg K, 74 kg Ca and 16 kg Mg ha^{-1} (Mulonguy and Kang, 1986). The effects and recycling of these nutrients in alley cropping systems are not well understood, however, and deserve further attention.

Crop yield. A. Atta-Krah (ILCA, Ibadan, Nigeria, unpublished data) found that the yield of alley-cropped maize increased by about 32% on average over sole-cropped maize. Other studies have also shown significant maize yield increases due to alley cropping (Kang et al, 1981a, 1981b).

Mulonguy and Kang (1986) observed that despite the considerable biomass and N yields from leucaena hedgerows, supplemental N was still required to obtain high crop yields. This may be because the conversion efficiency of N from prunings is rather low—apparently not more than 33% (Guevarra, 1976). However, slow mineralisation could be advantageous in areas of high rainfall and leaching: Read et al (1985) observed that whereas leucaena prunings had a beneficial effect on the subsequent maize crop, no such effect was observed with calcium ammonium nitrate. The factors controlling the mineralisation rate of N from prunings need to be studied in greater detail.

Soil moisture. Kang et al (1985) reported that using leucaena prunings for mulching increased soil moisture content. Further studies are needed on the effects of mulching on the physical properties and biological life of mulched soils to validate this observation.

Erosion control. Alley cropping may help control erosion (Brewbaker and Hutton, 1979). To improve the cultivation of heavy clay soils in the Ethiopian highlands, ILCA designed a simple, ox-drawn mouldboard plough for the construction of 4-m wide, level terraces. In addition, alley cropping with *Sesbania sesban,* an indigenous legume shrub, is being tested in the area. The preliminary results show that terrace farming with forage legumes can stabilise agricultural production in marginal areas through better soil, water and nutrient conservation.

Long-term effects. Alley cropping is beneficial to the long-term productivity of continuously cultivated land, thus contributing to sustainable crop production. Kang et al (1985) found that leucaena prunings maintained maize yields at 2 t ha^{-1}, while the yield on the control plot dropped to 0.3 t ha^{-1} after 5 years of continuous cultivation. Similar studies with *Sesbania sesban* are in progress in the Ethiopian highlands.

Alley cropping appears to be a technology suitable for smallholder farming systems for two primary reasons: it fulfills the main functions of trees in the traditional bush fallow system (aiding nutrient recycling and providing green manure, firewood and staking material) and combines the cropping and fallow periods, thus enabling longer continuous cropping. In addition, alley cropping can provide high-protein feed for livestock

Intercropping

While intercropping grain legumes with non-legumes is common in Africa (Okigbo and Greenland, 1977), the same cannot be said of forage legumes (Norman, 1982). However, because African farmers are familiar with the concept, the introduction of forage legumes into the traditional cropping systems should be possible.

Studies conducted by ILCA in Kaduna, Nigeria, and Debre Zeit, Ethiopia, show that intercropping cereals with forage legumes can be very productive in terms of biomass and protein yields. The economic analysis of the system has not yet been conducted, but several technical aspects of intercropping have been fairly well investigated.

Date of planting. The effect of date of undersowing *Trifolium steudneri* on the grain and DM yields of maize fertilized with N at 60 kg ha^{-1} was studied at Debre Zeit in 1985 (I. Haque, ILCA, Addis Ababa, Ethiopia, unpublished data). While grain yield was not significantly affected by the presence of the legume, stover yield was significantly lower than the control (Table 4). The DM yields of *T. steudneri* show a highly significant decreasing linear trend, and there is no evidence of a significant deviation from that trend (Table 4).

Table 4. *Effect of date of planting on grain and stover yields of maize and dry-matter (DM) yields of* Trifolium steudneri *on an upland soil, Debre Zeit, Ethiopia, 1985*.

Treatment	Planting date for trifolium after maize planting (weeks)	Maize[1]		Trifolium DM yield (kg ha^{-1})
		Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	
Maize (control)	n.a.[2]	4698	6273	n.a.
Maize + TS[3]	0	4201	4034	754
Maize + TS	1	4196	3877	603
Maize + TS	2	5028	4809	427
Maize + TS	3	5021	4616	283
Maize + TS	4	4311	4428	240
Maize + TS	5	4517	4178	144
Maize + TS	6	4533	4237	13
LSD[4]	0.05	n.s.[5]	1179	–

[1] Maize fertilized with 60 kg N ha^{-1}
[2] n.a. = not applicable.
[3] TS = *Trifolium steudneri*
[4] LSD = least significant difference.
[5] n.s. = not significant.
Source: I. Haque (ILCA, Addis Ababa, Ethiopia, unpublished data).

Mohamed-Saleem (1985) observed that in the subhumid zone of Nigeria, the effect of date of undersowing on food grain yield varied with the forage legume used. For instance, planting *Stylosanthes guianensis* cv Cook or *S. hamata* cv Verano on the same date as sorghum reduced the grain yield of sorghum by over 70%, but when they were sown 6 or 3 weeks later, the grain yield reduction was lower. If the cereal and the forage legume are planted on the same day, other, less productive but less competitive legumes than stylo should be used. Table 5 shows that the reductions in the grain yield of sorghum were related to the DM yield of the legume. Similar results were obtained by L.A. Nnadi and I. Haque (ILCA, Addis Ababa, Ethiopia, unpublished data) in central Ethiopia (Table 6).

Table 5. *Effect of intercropping on sorghum grain and stover yields and legume dry-matter (DM) yield, subhumid zone of Nigeria, 1985.*

Cropping system	Sorghum		Legume DM yield ($kg\ ha^{-1}$)	Total fodder ($kg\ ha^{-1}$)
	Grain yield ($kg\ ha^{-1}$)	Stover yield ($kg\ ha^{-1}$)		
Sorghum (sole)	1296	4667	n.a.[1]	4667
Sorghum + *Stylosanthes hamata*	313	1685	2778	4663
Sorghum + *Stylosanthes guyanensis*	388	1555	2063	3618
Sorghum + *Macroptylium atropurpureum*	356	2111	1296	3407
Sorghum + *Centrosema pascuorum*	1019	2981	926	4185
Sorghum + *Alysicarpus vaginalis*	1092	2519	926	3445
Sorghum + *Macroptylium lathyroides*	1297	2741	1481	4222

[1] n.a. = not applicable.

Source: Mohamed-Saleem (1985).

Table 6. *Maize grain yields and legume dry-matter (DM) yields on an upland soil, Debre Zeit, Ethiopia, 1985*.

Cropping system	Maize grain yield		Legume DM yield ($kg\ ha^{-1}$)
	$kg\ ha^{-1}$	Percent of control	
Maize (sole)	2215	n.a.[1]	n. a.
Maize + *Trifolium steudneri*	1316	59.4	2504
Maize + *Lablab purpureus*	995	44.9	3170
Maize + *Vicia dasycarpa*	1213	54.8	2513
Maize + *Medicago polymorpha*	1580	71.3	1039

[1] n. a. = not applicable.

Source: L. A. Nnadi and I. Haque (ILCA, Addis Ababa, Ethiopia, unpublished data).

Planting geometry. Attempts to maintain the yield of cereal crops in intercropping systems have necessitated the manipulation of the planting pattern. Mohamed-Saleem (1986a) reported that if the population of the intercropped cereal is the same as when it is planted as a sole crop, then grain yield reduction is minimal. However, a trial with maize, sorghum and lablab showed that there is an interaction between the legume and the cereal; although the effects of spatial arrangement were not very different between plots, intercropping maize with lablab appeared to be highly advantageous, but sorghum and lablab were incompatible (Table 7).

Table 7. *Effect of intercropping system on land-equivalent ratios of sorghum and maize dry-matter and grain yields, Debre Zeit, Ethiopia, 1984*.

Cropping system	Land-equivalent ratio	
	Dry matter	Grain
Sorghum (sole)	1.00	1.00
Sorghum/lablab (1:1)	0.81	1.04
Sorghum/lablab (2:1)	1.07	1.07
Sorghum/lablab (between normal rows)	0.96	1.05
Sorghum/lablab (mixture)	1.00	0.99
Maize (sole)	1.00	1.00
Maize/lablab (1:1)	0.86	1.54
Maize/lablab (2:1)	0.95	1.58
Maize/lablab (between normal rows)	1.07	1.43
Maize/lablab (mixture)	1.04	1.54

Source: I. Haque (ILCA, Addis Ababa, Ethiopia, unpublished data).

In another trial at Debre Zeit, maize (*Zea mays* cv Katumani) was intercropped with three forage-type cowpeas in various combinations (Table 8). The combined DM yields were generally equal to or greater than those from sole maize or sole cowpeas. The highest combined DM yield at harvest (13 t ha^{-1}) was achieved with cowpea cv White Wonder Trailing. When compared with sole maize, the reductions in the grain yield of intercropped maize were 14 to 25%.

Table 8. *Mean dry-matter and grain yields of maize intercropped with forage-type cowpeas, Debre Zeit, Ethiopia, 1986.*

Cropping system[1]	Grain yield				Dry-matter yield			
	Maize		Cowpea		Maize		Cowpea	
	t ha^{-1}	Percent reduction	t ha^{-1}	Percent reduction	t ha^{-1}	Percent reduction	t ha^{-1}	Percent reduction
Sole maize	5.11	n.a[2]	n.a.	n.a.	10.83	n.a.	n.a.	n.a.
Maize/cowpea I[3]	4.14	19	0.48	85	7.91	27	1.30	84
Maize/cowpea II[4]	3.81	25	0.92	68	8.05	26	4.90	56
Maize/cowpea III[5]	4.37	14	0.61	71	9.54	12	1.98	63
Sole cowpea I	n.a.	n.a.	3.31	n.a.	n.a.	n.a.	7.91	n.a.
Sole cowpea II	n.a.	n.a.	2.92	n.a.	n.a.	n.a.	10.87	n.a.
Sole cowpea III	n.a.	n.a.	2.14	n.a.	n.a.	n.a.	5.41	n.a.

[1] The planting ratio for all maize/cowpea intercrops was 3:1.
[2] n.a. = not applicable.
[3] Cowpea I = cowpea cv TVU. 1977 ODO2
[4] Cowpea II = cowpea cv White Wonder Trailing.

[5] Cowpea III = cowpea cv Black Eye Pea EXD3.
Source: C. S. Kamara and I. Haque (ILCA, Addis Ababa, Ethiopia, unpublished data).

Sanchez (1982) noted that legume–cereal intercropping is extremely site specific and weather dependent. Moreover, the type of intercropping system to be used should be validated locally, particularly in terms of relative planting dates, seed rates, row spacing, crop varieties and soil fertility.

Other intercrop-type systems

ILCA and IITA have investigated three other intercrop-type systems in highland Ethiopia and in Nigeria.

Sequential cropping

Sequential cropping is possible where the rainy season is fairly long or supplemental irrigation is available, or where the soil has a high moisture-retention capacity, as is the case with deep Vertisols. Sequential cropping on Vertisols is facilitated by the broadbed and furrow (BBF) technology: the results of a study at Debre Zeit show that the land-equivalent ratio (LER) of maize intercropped with medic and sequentially cropped with chickpeas was higher than that of other cropping systems that were investigated (Table 9).

Table 9. *Land-equivalent ratios for various multiple-cropping systems on a Vertisol, Debre Zeit, Ethiopia, 1985.*

Cropping system	Land-equivalent ratio
	Grain yield
Maize (sole)	1.0
Maize + vetch (inter) + chickpea (relay)	0.91
Maize + medic (inter) + chickpea (relay)	1.38
	Stover yield
Maize (sole)	1.00
Maize + clover	0.98
Maize + lablab	1.29
Maize + vetch (inter) + chickpea (relay)	1.30
Maize + medic (inter) + chickpea (relay)	1.31
	Total biomass
Maize (sole)	1.00
Maize + clover	1.03
Maize + lablab	1.19
Maize + vetch (inter) + chickpea (relay)	0.96
Maize + medic (inter) + chickpea (relay)	1.18

Source: I. Haque (ILCA, Addis Ababa, Ethiopia, unpublished data).

Deep-rooted legumes capable of utilising subsoil moisture are preferred as sequential crops. These include lablab, chickpea, *Stylosanthes scabra* and alfalfa. Legumes used for sequential cropping should also be capable of utilising nutrients efficiently, especially P.

Live mulches

The use of leguminous live mulches (eg. *Arachis repens, Desmodium triflorum, Centrosem pubescens, Psophocarpus tetragonolobus* and *Indigofera spicata*) with maize has been reported to be promising (Akobundu and Okigbo, 1984; Mulonguy and Kang, 1986). However, it appears that the mulches may compete with cereal crops for nutrients and water (Greenland, 1985). Also, the growth of live mulches often needs to be controlled either by frequent weeding or the application of a growth hormone (Akobundu, 1980). The extra expenditure on weeding and spraying reduces the usefulness of the system and makes adoption difficult.

Intersod planting

Intersod planting is a system where a cereal is planted between swards of a forage legume. The growth of the legume is controlled by herbicide application before planting the cereal. ILCA's results in Kaduna, Nigeria, were not promising because the legume used *(Stylosanthes hamata* cv Verano) reemerged early to compete with the cereal. The method is unlikely to be widely adopted by smallholder farmers.

OTHER STUDIES

Even though research on the role of forage legumes in farming systems has been intensified in the past few years, there are still areas, such as interspecies N transfer, biological nitrogen fixation, and residual effects of intercropping, that need to be clarified before the economic feasibility of using forage legumes in the traditional African production systems could be assessed.

Interspecies nitrogen transfer

Although the actual mechanism by which N is transferred between annual forage legumes and cereals is not well understood, benefits either in the grain yield or the N content of the cereal crop have been observed. For instance, Agboola and Fayemi (1972) reported that when maize was interplanted with mungbean *(Phaseolus aureus),* the grain yield of maize increased over the control. The amount of N transferred from the legume to maize was equivalent to a fertilizer application of N at 45 kg ha^{-1} Calopo *(Calopogonium mucunoides)* and cowpea did not have such an effect on maize grain yield. L. A. Nnadi and I. Haque (ILCA, Addis Ababa, Ethiopia, unpublished data) found that the N content in the grain and stover of maize intercropped with vetch on a low-N soil was higher than that of the control and comparable to that obtainable with N at 50 kg ha^{-1} (Table 10).

Table 10. *Nitrogen (N) content of maize grain and stover as affected by nitrogen application and intercropping with forage legumes, Debre Zeit, Ethiopia, 1985.*

Treatment	N content (%)	
	Grain	Stover
Maize	1.54	0.38
Maize + 50 kg N ha^{-1}	1.67	0.50
Maize + 100 kg N ha^{-1}	1.82	0.55
Maize + 150 kg N ha^{-1}	1.91	0.68
Maize + *Trifolium steudneri*	1.47	0.44
Maize + *Lablab purpureus*	1.55	0.40
Maize + *Vicia dasycarpa*	1.66	0.48
Maize + *Medicago polymorpha*	1.59	0.42

Source: L. A. Nnadi and I. Haque (ILCA, Addis Ababa, Ethiopia, unpublished data).

These and other studies suggest that not all legumes are suitable for interspecies N transfer, and those that do transfer N are not consistent. Chamberlain et al (1986) reported that when conditions are good for the establishment and early growth of legumes, competition occurs between the legume intercrop and maize. They did not find any evidence of a positive contribution by any of the studied legumes to the N economy of maize.

Biological nitrogen fixation

The ability of a legume to improve the soil N status depends partly on its N-fixing capacity. It appears that the higher the efficiency of N fixation by a legume, the less dependent the legume will be on soil N. This could increase residual soil N to a following crop, quite apart from the N contributed by roots. Studies on the proportions of N derived by forage legumes from biological fixation and from the soil are in progress at ILCA using the**,** ^{15}N technique.

Residual effects

The productivity of an intercropping system depends not only on the system's current values, but also on residual effects which determine how long continuous cultivation will be possible. The residual effects of pure and intercropped legumes cannot be assumed to be the same, since intercrops invariably produce much lower top yields and their root systems are probably less developed than the roots of legumes cultivated in pure stands. The effects of preceding crops and cropping systems on the grain and DM yields of cereals are being investigated by ILCA.

MAXIMISING NITROGEN INPUT INTO CROPPING SYSTEMS

The input of biologically fixed N into cropping systems can be maximised by selecting forage legumes for increased N-fixing capacity and higher N content, and by increasing biomass yield through better management.

Symbiotic N fixation

There is some evidence that the N-fixing ability of rhizobia is partly controlled by host genes (cf Viands et al, 1981; Heichel and Barnes, 1984). Viands et al, for instance, found a wide range of field performance in four successive harvests of alfalfa clones selected for contrasting N-fixing capacity under greenhouse conditions.

Nitrogen content of legumes

The amount of N contributed by legumes to the cropping system depends on the N content of the plant tissues that are to be left or incorporated in the soil. Annual forage legumes with a high root-N concentration appear to be particularly useful in short-term crop rotations, such as the cut-and-carry system where legume roots are the major contributors to soil nitrogen. L. A. Nnadi and I. Haque (ILCA, Addis Ababa, Ethiopia, unpublished data) found highly significant differences in the root-N content of various forage legumes (Table 11), and the rates of N transferred by these legumes in an upland soil of Ethiopia. Increases of 10–14% of whole-plant N concentration have been achieved through selection (Heichel and Barnes, 1984).

Table 11. *Total and water-soluble nitrogen (N) contents in the roots of forage legumes grown on an upland soil, Debre Zeit, Ethiopia, 1985.*

Legume	Total N (%)	Water-soluble N (%)
Trifolium steudneri (Debre Zeit)	1.91	0.59
Trifolium steudneri (Shola)	2.01	0.67
Vicia dasycarpa (ILCA accession no. 6795)	2.26	0.80
Vicia benghalensis sp	2.43	0.66
Vicia purpureus cv Rongai	1.10	0.21
Lablab purpureus cv Highworth	0.87	0.15
Medicago scutellata cv Snail	1.23	0.22
Medicago truncatula cv Barrel	2.08	0.62

Source: L. A. Nnadi and I. Haque (ILCA, Addis Ababa, Ethiopia, unpublished data).

Biomass yield

Increasing the N-fixing capacity of legumes and the N content of their tissues should be accompanied by increases in plant biomass. This depends largely on the management adopted: adequate fertilization with P, coupled with tillage practices that promote extensive root growth, should be pursued.

Trials in the Ethiopian highlands have shown that the DM yield of *Trifolium* sp. could be greatly increased by P fertilization (Akundabweni, 1984; Jutzi and Haque, 1985). Since large areas of sub-Saharan Africa are deficient in P, significant responses to P application by forage legumes can be expected (Haque et al, 1986). To gain a better understanding of the P response, studies involving various forage legume genera need to be conducted.

FORAGE LEGUMES AND LIVESTOCK IMPROVEMENT

More than 340 million tonnes of fibrous crop residues are produced in Africa annually (Kossila, 1985). They constitute an important source of animal feed, but are high in lignocellulosic compounds, which affect protein digestibility and voluntary intake (Mosi and Butterworth, 1985b). The nutritive value of crop residues could be improved by the use of strong alkalis and ammonia; however, these chemicals are expensive and not readily available in rural areas (Mosi and Butterworth, 1985a). Although useful in emergency situations, for example when livestock are threatened as a result of drought, supplementing crop residues with legumes appears to be more practical under normal conditions.

Supplementation with legumes has been shown to increase the digestibility of poor-quality roughages (Devendra, 1982), or their intake (Mosi and Butterworth, 1985b), or both (Minson and Milford, 1967; Lane, 1982; Moran et al, 1983). In an ILCA experiment with sheep, the total intake and digestibility of cereal straw was increased by the addition of 45% of *Trifolium tembense* hay to the base diet (ILCA, 1984). Higher DM intake was associated with lower levels of neutral detergent fibre (NDF) in the total ration and with a decreased straw consumption. This was confirmed in a follow-up trial which also showed that when both trifolium and a molasses/urea mixture were added to wheat straw, total DM intake was highest and digestibility increased by more than 200% (ILCA, 1985).

The increased DM intake and nutrient digestibility of total diets have been shown to result in better animal performance. For instance, culled oxen supplemented with *T. tembense* hay over a period of 63 days gained 362 g day^{-1}, more than twice as much as oxen fed poor-quality grass alone (163 g day^{-1}) (ILCA, 1985). In a second experiment with three different protein sources, the highest daily weight gain was recorded with a trifolium/*noug* supplement (357 g), followed by *noug* (314 g) and trifolium (114 g). Highland sheep fed diets enriched with legume hay grew faster than unsupplemented animals, and the effects of supplementation on total feed intake, nutrient digestibility, N retention and sheep growth rates were associative (ILCA, 1986).

Olayiwole et al (1986) reported that trifolium hay increased the intake of rations based on wheat straw but did not have any effect on the intake of teff-based rations. Weight gains increased when trifolium was included in the rations. The increased DM intake associated with trifolium hay might be due either to bypass protein provided by the legume or to an increased availability of amino acids, peptides or branched-chain fatty acids in the rumen, which in turn would increase the yield of rumen microbial protein (Van Soest, 1982).

ILCA studied the potential of *Sesbania sesban, Acacia cynophylla* and *A. seyal* as supplements to a basal diet of teff straw for growing sheep, by comparing them with vetch hay. *S. sesban* appears to be promising, with higher average growth rates (48 g day^{-1}) than when sheep were supplemented with vetch hay (39 g day^{-1}) (ILCA, 1986). The animals gained 11 g day^{-1} with *A. cynophylla* and about 45 g day^{-1} with *A. seyal,* but only towards the end of the experiment. The differences in the effects of these browse species on average daily weight gain and N balance of sheep are related to differences in the quantity and type of tannins and phenolics present in the forage.

In another ILCA experiment, sheep and goats were compared in their ability to use cereal straw and fruits from acacia trees as feed. Its results suggest that while sheep can utilise cereal residues better than goats, the latter are much better utilisers of legume fruits, probably because they are less susceptible than sheep to a digestive-tract toxin in the fruits (ILCA, 1986).

A study on animal offtake at Kurmin Biri, northern Nigeria, revealed that herds with access to fodder banks can maintain their size from birth, whereas those without access to fodder banks would decline in size. Herd owners who did not have fodder banks depended on purchases of animals and transfers to relatives to maintain the size of their herds (ILCA, 1987).

Supplementing Boran calves with 650 g of *Medicago sativa* hay per day and providing them with extra water gave a growth rate (108 kg) comparable to that of calves receiving all their dams' milk (114 kg). It was concluded that supplementation with legume hay and water is an adequate alternative to rearing calves on milk only (ILCA, 1987). Also, since the supplemented animals were valued higher than the unsupplemented ones, pastoralists could benefit by higher animal prices without reducing milk offtake for human consumption.

CONCLUSION

The evidence accumulated over the past few years suggests that forage legumes are a suitable means of injecting biologically fixed N into African crop–livestock production systems. They contribute to sustainable agricultural production by enhancing soil fertility, which in turn leads to increased crop production, and by improving the quality of animal feed, which appears to be one of the major constraints to livestock production in sub-Saharan Africa.

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