Soil-Related Constraints on the Production of Herbaceous and Tree Legumes in Sub-Saharan Africa and Thier Alleviation

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ABSTRACT

In sub-Saharan Africa, seventy four percent of the farmers and stockowners are smallholders. Soil nutrients and water are the main constraints for legume-crop-livestock output in smallholder production system. Legume forages can provide high quality feed for livestock in the dry season while improving the soil fertility either through their direct contribution to soil fertility or the better quality manure produced from feeding them to the livestock.

The paper summarizes the available information and ongoing research at ILCA on soil-related constraints with special reference to P, S, K, micronutrients, soil acidity and rhizobium on legumes and their alleviation. Maximizing nitrogen input through species/cultivars selection and management options are also highlighted.

Introduction

The farmers and stockowners of Africa are predominantly smallholders. They own single family farms of a few hectares, producing a mixuure of food crops and livestock. Only about 6% of Africa's cattle are on ranches ; 20% held by pastoralists and the remaining 74% are on small farms (Brumby, 1986).

Tothill *et al.* (1989) reported that since the smallholder crop-livestock farm will remain the ultimate level of intensive farming for a considerable time to come in much of Africa, there remains a strong basis for developing technologies which will enhance the productivity of this basic system. The system optimizes the benefits to be derived in developing the linkages between crop and livestock production in terms of the efficient use of soil, water and nutrients, land and labour, crop and livestock products.

Leguminous forages can provide both improved nutrition to livestock by supplementing the low quality feeds available, such as crop residues and natural pasture during the dry season, while improving the fertility, either through their direct contribution to soil fertility or the better quality manure porduced from feeding them to the animals, with the resultant improvement or maintenance of crop yields (Tothill *et al.*, 1989).

The diversity of the resource base (climate, soil and people), crops and cropping systems and livestock management systems encountered in sub-Saharan Africa prevents a precise discussion of constraints. Nevertheless some major constraints and their alleviation on herbaceous and tree legumes are discussed.

Water excess/stress

Drylands are both *thirsty* and *hungry* and rapid development of leguminous forages should be based on efficient water use efficiency and nutrient cycling in various crop-livestock production systems.

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Waterlogged soils are common in the highlands and tropical areas of Africa. In the Ethiopian highlands, the top-yielding African clovers grow best on seasonally waterlogged soil. *Sesbania rostrata*, which forms stem nodules, has five to ten times more nodules than the best nodulated crops, and has outstanding potential for N fixation in flooded soils (Dreyfus and Dommergues, 1981).

Both water excess/stress can have adverse effects on nodulation and N fixation and are considered to be one of the most neglected areas of study on legume-rhizobium association.

Nutrition

Nutritional deficencies and excesses may affect N fixation in legumes directly through adverse effects on root infection, nodule development and nodule function, and indirectly through effects on host plant growth. Table 1 shows the distribution of soil constraints in various agro-ecological zones of Africa.

Table 1 Physico-chemical soil constraints to production (thousands of ha, and (%) of the African Region)

Region	Total land area	Physical constraints				Chemical constraints						
									Excess			
		Steep slope	Sandy texture	Specific management problems	Low nutrient retention	Aluminum toxicity	Phophorus fixation	Low potassium	Soluble salts	Sodium	Calcium carbonate	Sulphate acidity
Mediterranean and arid North Africa	600.2	62.1 (10.4)	129.9 (20.5)	344.5 (57.4)	105.2 (17.5)	>0.1 (0.0)	>0.1 (0.0)	>0.1 (0.0)	25.5 (4.3)	1.6 (0.3)	104.9 (17.5)	>0.1 (0.0)
Sudano-sahelian Africa	828.2	50.9 (6.2)	277.4 (33.5)	370.2 (44.7)	310.9 (37.5)	35.6 (4.3)	14.7 (1.8)	28.5 (3.4)	19.7 (2.4)	12.0 (1.5)	25.1 (3.0)	0.7 (0.1)
Humid and sub-humid West Africa	206.6	15.3 (7.4)	57.5 (27.8)	63.0 (30.5)	111.9 (54.2)	67.1 (32.5)	38.1 (18.4)	86.3 (41.8)	3.0 (1.5)	3.9 (1.9)	0.6 (0.3)	1.8 (0.9)
Humid Central Africa	398.8	11.9 (3.0)	118.1 (29.6)	35.7 (9.0)	319.0 (80.0)	317.7 (79.7)	196.5 (49.3)	289.5 (72.6)	0.7 (0.2)	0.3 (0.1)	>0.1 (0.0)	0.4 (0.1)
Sub-humid and mountain E. Africa	251.0	54.6 (21.8)	19.1 (7.6)	52.2 (20.8)	60.7 (24.2)	45.5 (18.1)	34.0 (13.6)	60.8 (24.2)	12.3 (4.9)	6.2 (2.5)	22.2 (8.8)	0.7 (0.3)
Sub-humid and semi-arid southern Africa	559.2	49.1 (8.8)	271.4 (48.5)	51.1 (9.1)	387.8 (69.3)	169.1 (30.2)	99.2 (17.7)	171.9 (30.7)	14.4 (2.6)	7.0 (1.3)	31.8 (5.7)	0.2 (0.0)
Total Africa	2844.0	244.1 8.6	866.4 30.5	916.7 32.2	1295.5 45.6	635.0 22.3	382.5 13.5	637.0 22.4	75.6 2.7	31.0 1.1	184.6 6.5	3.8 0.1

Source: FAO (1986).

Phosphorus

Phosphorus is the most important nutrient in the successful establishment of legumes. In addition to its effect on dry matter yields of legumes, P often increases nodulation and hence increases crude protein content, P concentration or uptake by the plant. Phosphorus application may also increase the digestibility of dry matter (Haque and Jutzi, 1984 and Mohammed!Saleem *et al*., 1985). Phosphorus management with respect to forage legumes in sub-Saharan Africa has been reviewed by Haque *et al*. (1986). Sanginga *et al*. (1988a) reported that the application of 80 kg P/ha increased the dry matter yield and response of *Leucaena* to inoculation. Gobbina *et al*. (1989) also concluded that the application of P may be necessary to ensure proper nodulation, nitrogen fixation and growth of *Leucaena* and *Gliricidia* growth.

Cumulative effect of TSP and Egyptian rock phosphate (ERP) on clover dry matter production on Shola Vertisol over 6 years showed a linear and quadratic increase with increased rates of TSP ($Y=3579.40+149.29P$; $r=0.88$) and ERP ($Y=3767.49+309.91P-3.$

$01P^2$; $R^2=0.88$), respectively (ILCA, 1990).

Many African rock phosphates (PR) are low in chemical reactivity and are unsuitable for direct application. Alternative choices may be (1) to broadcast the RP and band a soluble source to provide P while the RP dissolves. This technique has been successful in Africa with locally available RP of low citrate solubility (Pichot and Roche, 1972) and (2) to use acidulated RP for various forage crops. Cumulative effect of TSP on an Ultisol over two years, increased the dry matter yield of lucerne significantly over the control (1,883kg/ha) when applied at 50, 100, 150 and 200kg P/ha. Dry matter production showed a quadratic response to TSP application ($Y=1865.35+19.10P-0.059P^2$; $R^2=0.86$). The application of 50% acidulated rock phosphate increased the dry matter yield significantly only at the highest rate of application and resulted in a linear increase in dry matter yield with increased rates of application ($Y=1987.73+5.41P$; $r=0.80$). The application of 25% acidulated rock phosphate and pure rock phosphate did not release enough P to produce a significant effect on lucerne yield (Haque, unpublished data).

Adapting plants to the soil's limitations rather than adapting the soil to meet forage requirements is another option for smallholder farmers. Large differences in the reponse of clover species and varieties to P classified into four groups by cluster analysis are shown in Fig. 1. Clover plants tolerant to low P are likely to show a lower P concentration in their tissues. Their nutritive value may thus be lower than that of other species/cultivars. Direct P supplemention to livestock in the form of salts to offset deficiency may be needed.

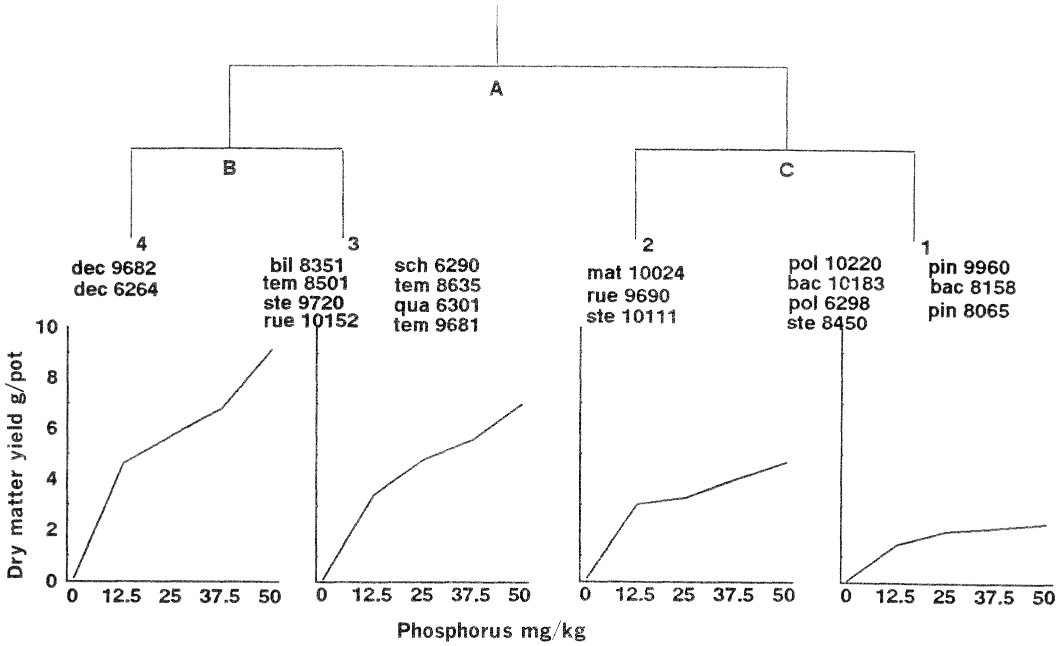

Fig. 1 Hierarchy for the classification of dry matter yield of clovers.
Source : Mugwira *et al.* (unpublished data).

Sulphur and potassium

Possibly because of the widespread use of fertilizers which contain S, such as single superphosphate, little attention has been given to the role of S in N fixation, despite its shortages in the soils of sub-Saharan Africa. However, good responses by forage legumes to elemental S and gypsum have been recorded in Uganda, Kenya and Nigeria (Haque and Jutzi, 1984). Forage legumes also responded positively to K applications in Swaziland and Uganda (Haque and Jutzi, 1984).

Micronutrients

Micronutrient deficiencies/responses in various crops and forages have been reviewed by Kang and Osimane (1985) and Haque (1987). Fertilizers to correct micronutrient deficiencies are not available in the region and also would be beyond the buying power of resource-poor farmers. A naturally occurring salt known locally as *Kanwa* has been identified as a cheap source of micronutrient (Mohammed-Saleem *et al.*, 1985). It has been used as mineral supplement for cattle in central and northern Nigeria.

Application of either *Kanwa* or P significantly increased the dry matter yield of *S. hamata*. The response to *Kanwa* was linear up to 100 kg/ha. Application of P and *Kanwa* also significantly increased the seed yield of *S. hamata*. Further analysis of the CP yield revealed that the application of 50kg *Kanwa*/ha (US $5.00) increased the CP yield of *S. hamata* by 200 kg/ha. Two hundred kg of CP in the form of cotton seed cake would cost about US$ 230 (Mohammed-Saleem *et al.*, 1985).

In view of the Mo role in nitrogen fixation, Mo is likely to become more important in Africa with the adoption of legumes in cropping systems. Studies on Mo toxicity in forages grown on soils with relatively prolonged wetness, high pH and under sodic conditions merit special attention (Haque, 1987).

Soil acidity

Large areas of African soils with serious nutrient limitations are essentially acid and become more so under cultivation, especially in heavy rainfall areas and if N fertilizers are used. Aluminium, Mn and Fe toxicities are the common problems for plant growth on these soils (Table 1).

Acidity can be easily corrected and, as the pH rarely needs to be raised beyond 5.5, the amounts of lime needed to do so are generally not large. Temperate legumes like lucerne and subterranean clover do not grow or nodulate well in acid soils. Studies carried out for a period of three years on the effect of lime (2,6 and 10 t/ha) and P (75,150 and 300 kg P/ha) on the dry matter yield of lucerne grown on an Ultisol showed that P significantly increased the dry matter yield of lucerne and gave a quadratic response to P application. On the other hand, lime also significantly increased the dry matter yield of lucerne except for on application of 2 t/ha. Dry matter yield showed a linear increase with increased rates of lime applied (Tekalign and Haque, unpublished data).

Soil acidity can also be corrected by manure application in crop-livestock systems. We are looking at the long-term effect of manure (0 to 10t/ha) on lucerne (cv. Hunter River) grown on an Ultisol. Application of manure at 4, 6, 8, and 10 t/ha significantly increased the dry matter yield as compared with the control (291 kg/ha) (Fig. 2). Dry matter showed a linear increase with increased rates of manure applied ($Y=158.93+193.17M$; $r=0.90$) (ILCA, 1990).

Some tropical legumes seem to be adapted to acid soils and often suffer from micronutrient imbalance once the pH rises above 5.5. The local *Trifolium Africanum* nodulated and fixed N at a pH of 4 when a sufficient level of Ca was available whereas the European species, *Trifolium pratense*, failed to nodulate (Small, 1968). Odu *et al.* (1971) found that *S. guianensis* and *C. pubescens* nodulated effectively and grew best under Nigerian acid soils.

At ILCA, we are screening herbaceous and tree legume germplasm with respect to acid soils which are deficient in P and contain toxic levels of Al or Mn or both. Preliminary results indicated that there is a wide variability in species and cultivars with respect to Al/Mn

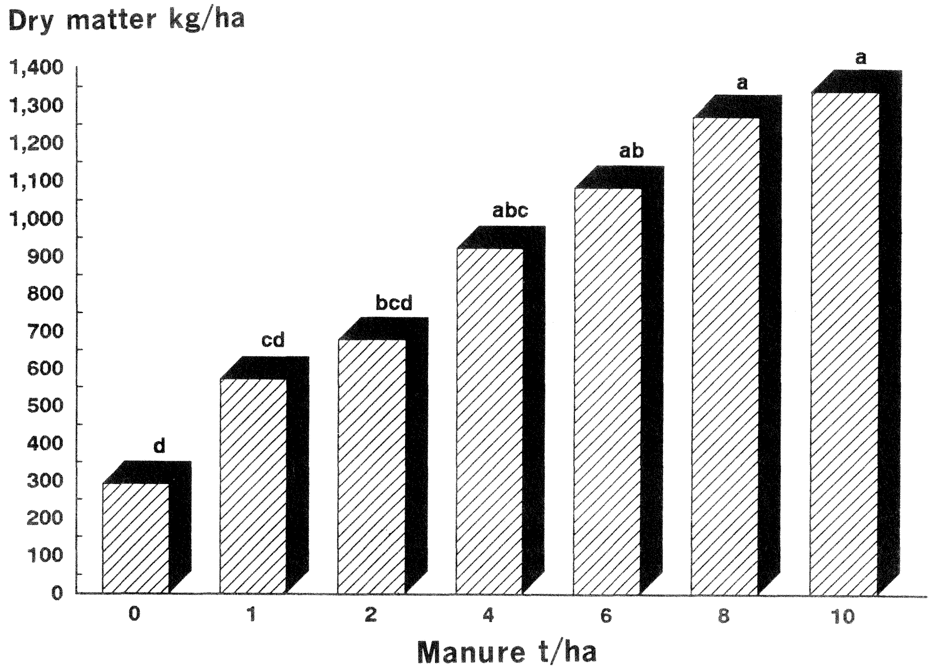

Fig. 2 Effect of manure on lucerne grown on Ultisol, Soddo, Ethiopia.
Source : Haque (unpublished data).

toxicities.

Soil salinity

There are approximately 79.5 million hectares of salt and Na-affected soils in sub-Saharan Africa (Table 1). Salinity affects the soil chemical and physical properties making it unfit for conventional crop production. A complete solution of the problem of waterlogging and salinity requires a comprehensive drainage to remove the excess groundwater. This amounts to the construction of a very large network of drainage canals and is a gigantic task made more difficult by the small gradient to the sea (Malik *et al.*, 1986).

A possible approach could be to tailor plants to suit this environment. Studies conducted in Pakistan and India indicate that growing forages for the utilization of salt-affected soils is feasible and economical (Malik *et al.*, 1986 ; Kumar and Abrol, 1986). Given the recent abvances in the use of tissue culture for selection of salt-tolerant plants, it is likely that this major obstacle will be overcome by the use of these techniques.

Rhizobium

The presence or absence of the approporiate rhizobium in the soil dictates whether inoculation of the legume seed is required. Those species or cultivars which do not require inoculation have obvious advantages at the farm level.

There has been some controversy over the need to inoculate tropical legumes. On the one hand, it is argued that many tropical legumes will nodulate without inoculation (Norris, 1966) and there is an evidence from African sources to support this statement (Haque and Jutzi, 1984).

Yet it is obvious that there are wide variations in the effectiveness of rhizobia isolated from different sites, and some of the indigenous strains may be of limited value to the host legume. It should also be remembered that rhizobium strains differ in their rates of N fixation, and just because a legume has formed nodules this does not mean that it will not respond to inoculation with a more effective N-fixing strain.

Obviously some tropical forage legumes exhibit rhizobium strain specificity comparable to that commonly associated with the temperate legumes. These species are *Leucaena leucocephala, Lotononis bainesii* and Stylosanthes (cv. Oxley fine stem) and form effective nodulation only with the aid of inoculation (de Souza, 1969).

In a greenhouse experiment, various strains of rhizobium (USDA 3786, 3110, 3781, 3782 and 3117) were compared on *Sesbania sesban* grown on Shola Vertisol. Strain 3117 significantly increased the number of nodules and shoot dry weight compared to other strains (Table 2). On the other hand, no significant effect of various strains was noticed on the shoot dry weight as compared with the control. Future studies on rhizobium screening are being carried out on undisturbed and disturbed soil. Similar studies are in progress on highland *Leucaena leucoephala*.

Table 2 Effect of rhizobium strains on *Sesbania sesban* 70 DAT on Shola Vertisol, Ethiopia

	Nodule number/pot	Shoot dry weight g/pot	Relative* effectiveness (%)
Control	0.00^{c}	0.133^{c}	4.1
Control+N**	0.00^{c}	2.750^{a}	100.0
Strain USDA			
3110	9.67^{bc}	0.320^{c}	11.6
3117	70.67^{a}	1.1117^{b}	40.6
3781	22.67^{b}	0.410^{c}	14.9
3782	12.00^{bc}	0.307^{c}	11.2
3785	3.67^{c}	0.190^{c}	6.9
3786	8.33^{bc}	0.297^{c}	10.8

Within columns, means followed by the same letter do not differ significantly at 5% level by Duncan's Multiple Range Test.

$$\text{*Relative effectiveness} = \frac{\text{Shoot dry weight of inoculated plants}}{\text{Shoot dry weight of nitrogen control}} \times 100$$

All the treatments were supplied with P (50mg/pot).

**N rate was 100mg/pot as urea.

Source: Luyindula and Haque (unpublished data).

In field trials, inoculation with elite strains gave yields similar to fertilizer application at 150kg N/ha, suggesting that levels of nodulation and nitrogen fixation were sufficient to provide the plants with their requirements for N. This suggests that the use of appropriate rhizobial strains could improve the nigrogen fixation and subsequent growth of *Leucaena* in soils deficient in N and *Leucaena* rhizobia (Sanginga *et al*., 1988a).

To assess the residual effect of inoculation and fertilization of *Leucaena*, the persistence and the symbiotic effectiveness of introduced rhizobia were studied in pots containing soil from field experiment. Soil from inoculated plots contained more rhizobia and promoted increased nodulation and shoot dry matter production (Table 3). Nodule typing indicated that only 17 and 7% of the nodules were due to the native rhizobia in uninoculated and inoculated plots with IRC 1050, respectively. In the inoculated plots the Rhizobium strain IRC 1045 fromed 89% of the nodules and only 2% were due to indigenous rhizobia. Nine percent of the

Table 3 Effect of previous inoculation treatments on nodulation and growth of *Leucaena* after 8 WAP

Previous inoculation treatments	Number of nodules/plant	Nodule fresh weight mg/plant	Shoot dry weight g/plant	Height cm
Uninoculated	18	105.00	1.67	55.50
Rhizobium IRc 1050	28	200.00	2.27	65.33
Rhizobium IRc 1045	28	232.50	2.79	74.75
LSD (5%)	5	62.50	0.27	4.46

Source : Sanginga *et al.* (1988b).

nodules were due to the introduced rhizobium strain IRC 1050. It can be concluded that if adequate strains of rhizobia are introduced in the soil, the populatipn will survive and eventually multiply over the years under the continuous *L. leucocephala* cropping without additional inoculation (Sanginga *et al.*, 1988b).

Cobbina *et al.* (1988) revealed that *Leucaena* inoculation with the two strains of rhizobium which improved the shoot dry matter and N uptake occasionally, was not as effective as the use of fertilizer N. Therefore, it is necessary to identify more effective strains of rhizobium for the acid soils of humid Nigeria.

The effect of prunings from *Leucaena* inoculated with the rhizobium strain IRC 1045 on the increase of maize grain yield was equal to that of fertilization with 80 kg N/ha. On the other hand, the maize grain yield obtained after the use of prunings from uninoculated *Leucaena* was low but comparable to that produced by N fertilizer at 40 kg N/ha.

Generally, the yield of maize was higher in the plot inoculated with rhizobium IRC 1045 than in the uninoculated ones and those inoculated with rhizobium IRC 1050 (Sanginga *et al.*, 1988c).

Sanginga *et al.* (1989) further reported that estimates with the ^{15}N dilution method gave a nitrogen fixation of 134 kg/ha in six months when *Leucaena* was inoculated with the rhizobium strain IRC 1045 and 98kg/ha for *Leucaena* inoculated with the rhizobium strain IRC 1050.

Maximizing nitrogen input into cropping systems

The input of biologically fixed N into cropping systems can be maximized by selecting species/cultivars for increased N-fixing capacity, higher N content and through management options.

There is some evidence that the N-fixing ability of rhizobia is partly controlled by host genes and Viands *et al.* (1981) found a wide range of field performance in four successive harvests of alfalfa clones selected for contrasting N-fixing capacity under greenhouse conditions. The amount of N contributed by legumes to the cropping system depends upon 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 useful in short-term rotations where legume roots are the major contributors to soil N.

In a greenhouse exeriment, the effect of management (rhizobium, P and combination) was investigated on *Sesbania goetzei* grown on Shola Vertisol. Inoculation with effective rhizobium along with P application significantly increased the shoot, root and total dry matter compared with other treatments (Table 4). Highest level of N derived from fixation was obtained with P and rhizobium treatment as compared with other treatments (Table 5).

In another study, no significant effect of drainage was noticed in various treatments and the interaction between drainage and various treatments was also not significant with respect to dry matter and biological nitrogen fixation. Phosphorus application to clover and wheat

Table 4 Effect of management on nodulation and growth of *Sesbania goetzei* on Shola Vertisol, Ethiopia

Treatments	Nodule per pot ··· Number	Dry weight mg	Shoot dry weight g/pot	Root dry weight g/pot	Total dry weight g/pot	Height cm/plant
Soil	0	0	0.230b	0.0525b	0.283b	2.520b
S. S.	0	0	0.390b	0.1475b	0.520b	3.465b
Rhizobium (R)	4	4.7	0.222b	0.1025b	0.330b	2.215b
Phosphorus (P)	0	0	0.260c	0.1225b	0.383b	2.900b
P+R	66	220	2.370a	0.7350a	3.325a	11.535a

Within columns, means followed by the same letter do not differ significantly at 5% land by Duncan's Multiple Range Test.

Source: Luyindula and Haque (unpublished data).

Table 5 Effect of management on shoot nitrogen yield derived from fixation in *Sesbania goelzei* on Shola Vertisol, Ethiopia

Treatments	mg N/pot
Soil	6.06ba (0.00)
S. S.	8.63b (0.00)
R	6.62b (1.05)
P	4.60b (0.00)
R+P	62.72a (60.40)

Within column, means followed by the same letter do not differ significantly at 5% level by Duncan's Multiple Range Test. Values in parentheses indicate nitrogen derived from fixation in mg N/pot

Source: Luyindula and Haque (unpublished data).

Table 6 Effect of drainage and phosphorus on dry matter yield and biological nitrogen fixation by clover on Ginchi Vertisol, Ethiopia

Treatments	BBF	Flat	Mean
	······Dry matter (kg/ha) ······		
1. *T. quartinianum*	455	418	436 b
2. *T. quartinianum* + *P*	2508	2185	2347 a
3. Wheat	622	847	735 b
4. Wheat+P	1794	1657	1275 a
Mean	1345 a	1277 a	
	·········Fixed kg N/ha ·········		
1. *T. quartinianum*	11.48	10.35	10.91 b
2. *T. quartinianum* + *P*	71.57	64.46	68.01 a
Mean	41.52 a	37.40 a	

Within columns or rows, means followed by the same letter do not differ significantly at 5% level of probability (Duncan's Multiple Range Test).

Source: Haque (unpublished data).

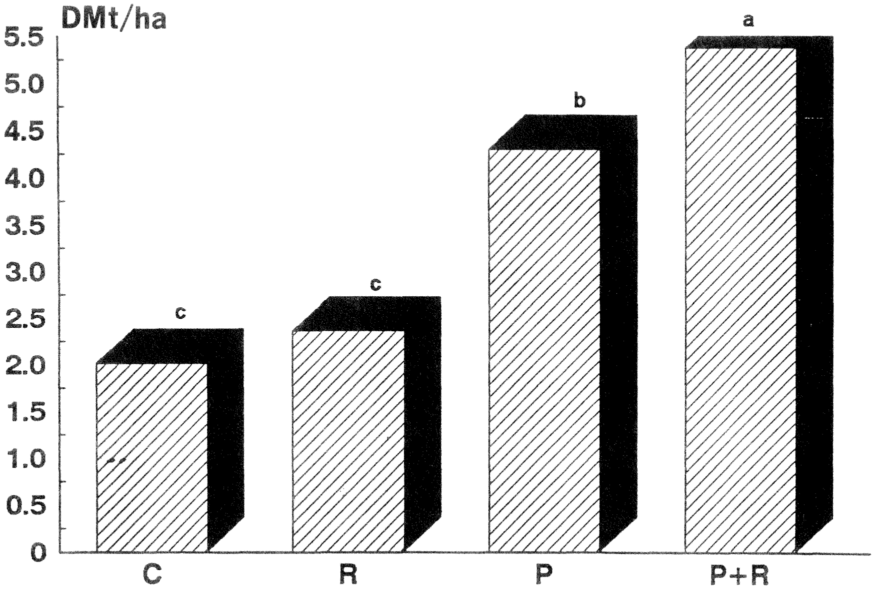

Fig. 3 Effect of management on dry matter yield of Desmodium on Ultisol, Soddo, Ethiopia.
Source : Haque (unpublished data).

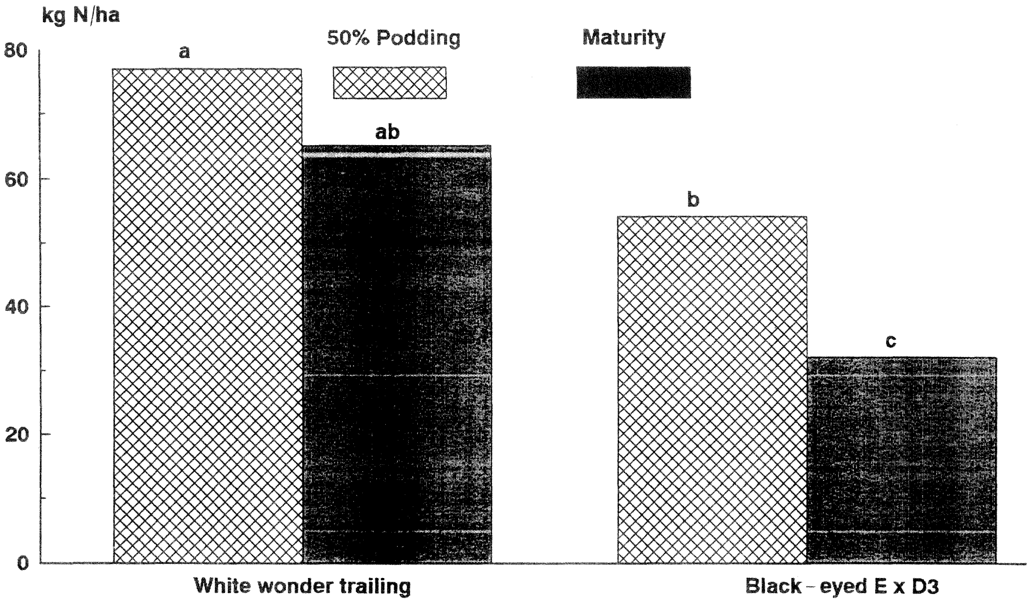

Fig. 4 Biological nitrogen fixation as affected by age of cowpea harvest on Vertisol, Ethiopia.
Source : Haque (unpublished data).

significantly increased the dry matter yield compared with the absence of P application. Phosphorus application also significantly increased the biological nitrogen fixation compared with the absence of P application (Table 6).

The effect of inoculation, P and their combination was also investigated on Desmodium grown on an Ultisol. Phosporus and combination of rhizobium and P increased the dry matter production significantly as compared with the control (Fig. 3).

The effect of two cowpeas cultivars and time of harvest on biological nitrogen fixation was investigated on a Debre Zeit Vertisol. At 50% podding, White wonder trailing and Black-eyed bean fixed 77 and 65 kg N/ha respectively. There was a reduction of 23 and 33kg N/ha in both cultivars indicating the transfer of fixed N to the grain (Fig. 4).

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Discussion

Kanwar, J. S. (India) : In the soils you described phosphorus is the limiting factor and not nitrogen.

Answer : If you apply phosphorus to a soil deficient in nitrogen, satisfactory results cannot be obtained. Both elements must be applied.