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LIMITING NUTRIENTS FOR BEAN PRODUCTION ON CONTRASTING SOIL TYPES OF LAKE VICTORIA CRESCENT OF UGANDA

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ABSTRACT

Common bean (*Phaseolus vulgaris* L.) is one of the most important grain legumes in East Africa, but its yield has remained below the genetic potential. Declining soil fertility is among the primary constraints to bean production in most East African bean producing regions. Often existing recommendations are generic and inept to guide farm level decision making on nutrient replenishment. A greenhouse nutrient omission study was conducted to determine the limiting nutrients in three soils of Masaka District, commonly cropped to beans: *"Liddugavu"* a Phaeozem, *"Limyufumyufu"* a Cambisol and *"Luyinjayinga"* an Umbrisol soil. Nine treatments; (i) complete nutrient treatment, (ii) N omitted, (iii) P omitted, (iv) K omitted, (v) Mg omitted, (vi) S omitted, (vii) Ca omitted, (viii) Micronutrients omitted and (ix) control without nutrients. Each treatment was randomly assigned to the three soils and replicated three times using a completely randomised design. Nitrogen, phosphorus and potassium were limiting nutrients for bean production in Umbrisol (*Luyinjayinja*) while in Cambisol (*'Limyufumyufu*), common bean production was most limited by soil acidity. The performance varied with soil types, with beans grown on the Phaeozem registering greater leaf number and growth, confirming both scientist's and local farmer's knowledge that this soil has greater potential than the other two soils.

Key Words: Cambisol, Phaeozem*, Phaseolus vulgaris,* Umbrisol

RÉSUMÉ

Le haricot commun (*Phaseolus vulgaris* L.) est un des légumes à grains les plus importants en Afrique de l'Est, mais son rendement reste toujours en dessous de son potentiel génétique. La baisse de la fertilité du sol est parmi les contraintes primaires à la production du haricot dans la plupart des régions productrices de l'Afrique de l'Est. Le plus souvent, les recommandations sont génériques et inadéquates pour guider la prise de décision au niveau champ sur le réapprovisionnement en nutriment. Une étude sous serre sur l'omission de nutriment a été conduite pour déterminer les nutriments limitants dans les trois sols du district de Masaka, communément utilisés pour produire du haricot : *"Liddugavu"* un sol du Phaeozem, *"Limyufumyufu"* un sol du Cambisol et *"Luyinjayinga"* un sol du Umbrisol. Neuf traitements, (i) traitement complet de nutriments, (ii) N omis, (iii) P omis, (iv) K omis, (v) Mg omis, (iv) S omis, (vii) Ca omis, (viii) micronutriments omis et (ix) control sans nutriments. Chacun des traitements a été aléatoirement distribué aux trois types de sols et répliqué trois fois dans un dispositif complètement aléatoire. Azote, phosphore, et potassium ont été les nutriments limitants pour la production du haricot dans

Umbrisol (*Luyinjayinja*) tandis que dans Cambisol (*'Limyufumyufu*), la production du haricoct commun a été limitée par l'acidité du sol. Les performances varient en fonction des types de sols, avec le haricot produit sur le Phaeozem comptant plus de feuilles et de croissance, confirmant à la fois les connaissances des scientifiques et des populations locales qui stipulent que le sol a un potentiel plus élevé que les deux autres sols.

Mots Clés: Cambisol, Phaeozem, *Phaseolus vulgaris,* Umbrisol

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is the most widely grown grain legume, and second only to maize as a food crop and a major source of food security in East Africa (Mauyo *et al.,* 2007). Bean production in Uganda primarily occurs in the central, eastern and western regions (Sibiko *et al.,* 2013). Farmers in the Lake Victoria crescent of Uganda mainly grow common beans on three soil types locally classified as: *Liddugavu* (Phaoezem), *Limyufumyufu* (Cambisol) and *Luyinjayinja (*Umbrisol) (Tenywa *et al.,* 2014). However, yields are still below the genetic potential (Anon., 2013).

In order to increase yield, some farmers have attempted to use inorganic fertilisers (1.3%), manure (8.7%) (UBOS, 2006) and inorganic foliar sprays (Kabuga *et al.,* 2015), but the response has not been consistent (Sanginga and Woomer, 2009) especially on Umbrisol and Cambisol soils.

In East Africa, limited N and P availability (Beebe *et al.*, 2010) is the major production constraint to bean production. This study was conducted to determine the most limiting nutrients in Phaeozem, Cambisol, and Umbrisol soils commonly used for bean production in Uganda.

MATERIALS AND METHODS

A two cycle potted experiment was conducted with the first cycle at the Makerere University Agricultural Research Institute Kabanyolo (MUARIK); while the second one at the National Agricultural Research Laboratories (NARL), Kawanda.

Study soil collection and preparation. The study soil was collected from three communities (Mukungwe, Kabonera and Lwankoni) in Masaka district located in central Uganda, at 31.7361°E latitude and 0.34111°S longitude on the three most agriculturally important soil types in farmer's fields. These soils were selected for study based on a series of farmer meetings from three communities, which indicated that these were the three most important, farmer-recognised soil series for common bean production. Soil samples were obtained in a zig-zag pattern at ten locations within each field, from a depth of 0 - 15 cm. A bulk sample of about 170 kg was obtained from an area of approximately 50 m x 100 m for each soil type. A total of about 500 kg of soil was taken for greenhouse experiment and laboratory analyses. Composite samples obtained from the bulk samples were air dried in a dust free area, and the portion to be used for nutrient omission study was disaggregated and crushed with a mortar and pestle to pass a 5-mm sieve (Johnston and Askin, 2005). The samples were subsequently used for physicochemical analyses, after crushing them to pass a 2-mm sieve.

Experimental design. The pot experiment was laid out in a completely randomised design (CRD), with nine treatments (Table 1). Each nutrient treatment was randomly assigned to portions of each of the three soils. Table 1 shows the treatments used in the experiment, while Table 2 shows the nutrient ingredients and application rates.

The experiment was conducted in plastic pots with 2.5 kg of soil in each pot. Common bean variety BAT 477 was selected as the test

TABLE 1. Treatments and nutrients applied in the omission study conducted at Makerere University Agricultural Research Institute Kabanyolo and National Agricultural Research Laboratories in Uganda

Nutrient treatment	Nutrients added
Control	No nutrients added
Complete nutrient treatment	N,P, K, Mg, Ca, S, Micronutrients
N omitted	P, K, Mg, Ca, S, Micronutrients
P omitted	N, K, Mg, Ca, S, Micronutrients
K omitted	N, P, Mg, Ca, S, Micronutrients
Mg omitted	N, P, K, Ca, S, Micronutrients
S omitted	N, P, K, Mg, Ca, Micronutrients
Ca omitted	N, P, K, Mg, S, Micronutrients
Micro nutrients omitted	N, P, K, Mg, Ca, S

TABLE 2. Nutrient stock solutions and application rates for the nutrient omission study conducted at Makerere University Agricultural Research Institute Kabanyolo and National Agricultural Research Laboratories in Uganda

Element	Nutrient application rate (kg ha^{-1})	Compound
N	100	Urea
P	100	$NaH_2PO_4.2H_2O$
K	100	KCl
Mg	35	$MgCl_2.6H_2O$
Ca	30	$CaCl_2$
S	25	Na_2SO_4
Fe	5	FeNaEDTA[a]
B	2	H_3BO_3
Mn	5	$MnCl_2.4H_2O$
Zn	4	$ZnCl_2$
Mo	3	$[NH_4]_6Mo_7O_{24}.4H_2O$
Cu	0.4	$CuCl_2.2H_2O$
Co	0.1	$CoCl_2.6H_2O$
Ni	0.1	$NiCl_2.6H_2O$

crop because of its acid tolerance characteristics and high nitrogen fixation ability (Kipe-Nolt and Giller, 1993) Four seeds were sown in each pot at planting, and later thinned to two plants per pot, five days after emergence (DAE).

The Hoagland (1950) nutrient solution was used for the micronutrient and the concentrations of the macronutrients were chosen based on concentration ranges proposed by Hewitt (1952).

Data collection. From eleven days after emergence (DAE), regular observations were made to detect occurence of visual nutrient deficiency symptoms on foliar parts of plants (Foli, 2012). The number of leaves per plant and the above ground dry matter production measurements were taken to monitor growth of beans. To accurately record the data for above ground dry matter, the experiment was closely monitored and fallen leaves captured and kept in labeled polythene bags. These were added to the dry matter after plant harvest and oven dried together. The two surviving plants were harvested at six weeks (42 days after planting) by cutting at the base of the plant. Plant fresh weight was recorded, then samples were oven dried at 70 ^{o}C for 72 hours, and weighed again for dry weight. Dry samples were ground and analysed for macro- and micronutrient concentrations.

Laboratory analyses. Total soil organic carbon was analysed using the dry combustion method; while available P was determined using Olsen method described in Okalebo *et al.* (2002). Exchangeable K^+ and Na^+ were determined using a flamephotometer, while Ca^{2+} and Mg^{2+} were determined using an atomic absorption spectrometer. Soil pH was measured in a 1 : 2.5 soil to water ratio using a pH electrode. The Kjeldahl method was used to determine total N (Bremner, 1965). Micronutrients were extracted in Mehlich 3 extractant solution (Mehlich, 1984). Micronutrients such as Cu, Mn and Zn were measured by atomic absorption, while Boron was measured by colorimetric (Berger and Truog, 1939). Soil texture was determined using hydrometer method (Bouyoucos, 1936).

Statistical analysis. The above ground dry matter and number of leaves per plant data were subjected to analysis of variance using GenStat edition 12. Mean separations were done using Tukey Multiple Comparison test (Tukey, 1949).

RESULTS

Initial physico-chemical properties. All the study soils had a textural class of sandy clay loam (Table 3). Bulk density was 1.4, 1.3 and 1.4 g cm^{-3} for Phaeozem, Cambisol, and Umbrisol, respectively. The concentrations of

TABLE 3. Initial physico-chemical properties of the three farmer identified soils used in the nutrient omission study in bean growing soils in Uganda

Soil types		%			mg kg^{-1}			cmol kg^{-1}		Textural class
	pH (H_2O)	OM	Total N	P^a	Fe^{2+}	Al^{3+}	K^+	Ca^{2+}	Mg^{2+}	
Phaeozem "*Liddugavu*"	6.91	2.14	0.16	21.10	129	932	5.86	26.30	17.5	SCL
Cambisol "*Limyufumyufu*"	5.02	2.05	0.12	3.62	149	1410	1.46	4.79	4.20	SCL
Umbrisol "*Luyinjayinja*"	5.13	1.92	0.09	2.24	151	1250	0.82	6.42	7.98	SCL
†Critical values	5.5	3	0.25	15	-	-	1.15*	3.12*	0.68*	-

[a]Olsen extractable, †Okalebo *et al.*, (2002), and *Rhoads(1982)

available phosphorus and nitrogen were below the critical levels in Cambisol and Umbrisol soils (Table 3). Olsen Extractable P and soil pH were above the critical levels in Phaeozem (Okalebo *et al.*, 2002).

Soil type and above ground dry matter production. Plants grown in Phaeozem yielded significantly ($P < 0.05$) higher above ground dry matter than did plants grown in other soil types (Fig. 1). For instance, plants grown in the Phaeozem soil yielded 27.7% and 33.6% greater ($P < 0.05$) above ground dry matter than those grown in Umbrisol and Cambisol, respectively. On the other hand, bean dry matter obtained from Umbrisol was closely similar to that of Cambisol (Fig. 1).

Effect of nutrient omission on dry matter production in Phaoezem. Plants grown in cases where N or Ca were omitted accumulated 16.3 and 23% respectively, lower above ground dry mater than those grown in the complete treatment, but they were not significantly different ($P > 0.05$) from plants grown the complete treatment (Fig. 2). The least above ground dry matter was realised from plants grown in the control treatment, which was also significantly ($P < 0.05$) different from the complete treatment (Fig. 2).

The above ground dry matter in the complete treatment was similar to that of the nutrient omission treatments for P, N and Ca, while the values obtained from S, K, Mg and micronutrients omitted treatments were significantly higher than those of the complete treatment. The highest above ground dry matter was with micronutrients omission which was significantly ($P < 0.05$) different from the –P, complete, -N, -Ca and the control, but not significantly ($P > 0.05$) different from the -Mg, -S, and –K (Fig. 2).

Nutrient omission and dry matter production in Umbrisol. Plants grown in the control and treatments where N, P and K were omitted accumulated significantly ($P < 0.05$) lower above ground dry mater than those grown in the complete treatment (Fig. 3). The least above ground dry matter was realised

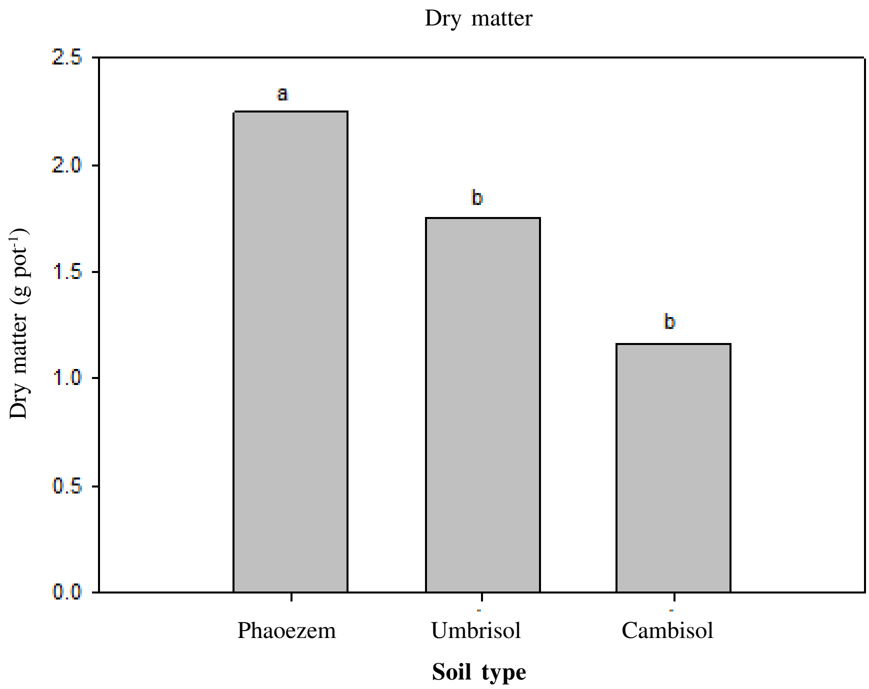

Figure 1. Above ground dry matter production under three soil types in Masaka District, Uganda.

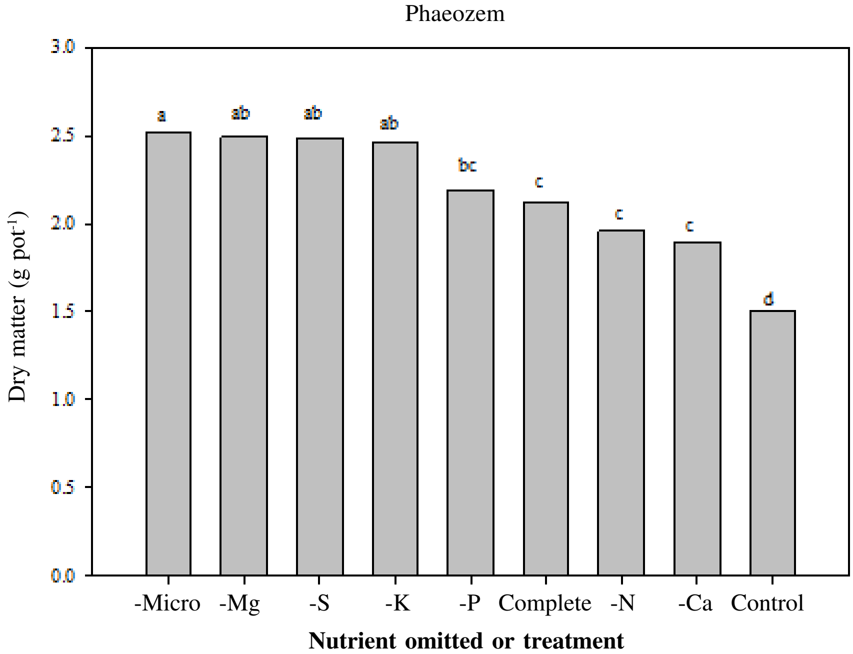

Figure 2. Above ground dry matter production in a Phaoezem in a nutrient omission study.

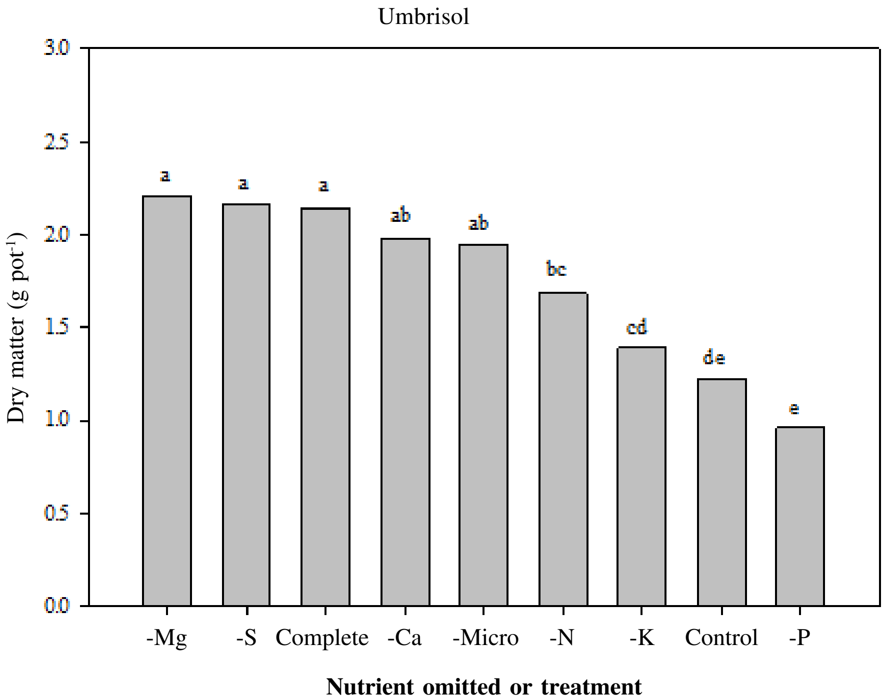

Figure 3. Bean above ground dry matter production in an Umbrisol in a nutrient omission study.

from the P omitted treatment, which was significantly ($P < 0.05$) lower than what was realised from the treatments where nitrogen and potassium were omitted (Fig. 3).

The above ground dry matter in the complete treatment was similar to that of the nutrient omissions for Ca, Mg, S and micronutrients. The highest above ground dry matter was in Mg omitted treatment; though, this was not significantly ($P > 0.05$) different from the complete, -Ca, -S, and -micronutirent treatments (Fig. 3).

Effect of soil type on number of leaves per plant. Plants grown in Phaeozem had significantly ($P < 0.05$) more leaves than plants grown in Cambisol and Umbrisol (Fig. 4). However, the number of leaves from beans grown in Umbrisol was not significantly different from that of the Cambisol.

Nutrient omission and number of leaves per pot in Cambisol. Plants grown in the control (without nutrients) in the Cambisol had the fewest number of leaves per plant, and they were significantly ($P < 0.05$) different from those in the complete nutrient treatment. Incidentally, the number of leaves in phosphorus and calcium omitted treatments were not significantly different ($P > 0.05$) from those in the complete treatment. The number of leaves in the complete treatment was similar to that of the nutrient omissions for Mg, micronutrients, N, S, Ca, P and K. The greatest number of leaves per plant was observed in K omitted treatment although it was not significantly ($P > 0.05$) different from the complete treatment (Fig.5).

Effect of treatment on number of leaves per pot in Umbrisol. In Umbrisol, the number of leaves in the complete treatment was similar to that of the nutrient omissions for Mg, Ca, micronutrients, S and K. The greatest number of leaves per plant was observed in Mg omitted treatment, although it was not significantly (P

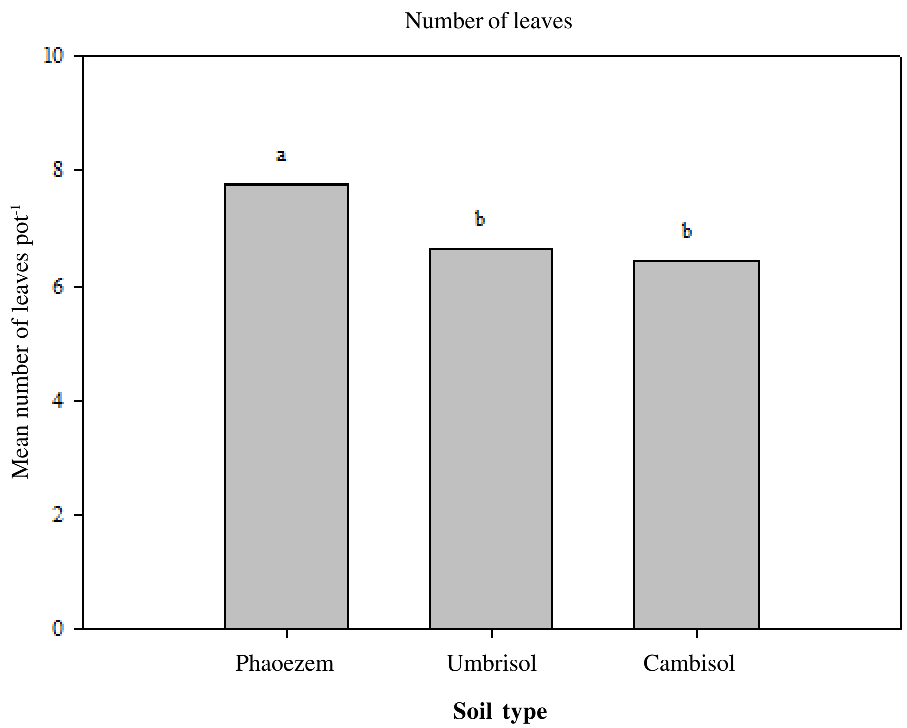

Figure 4. Number of bean leaves per pot growing on different soil types in Masaka District in Uganda.

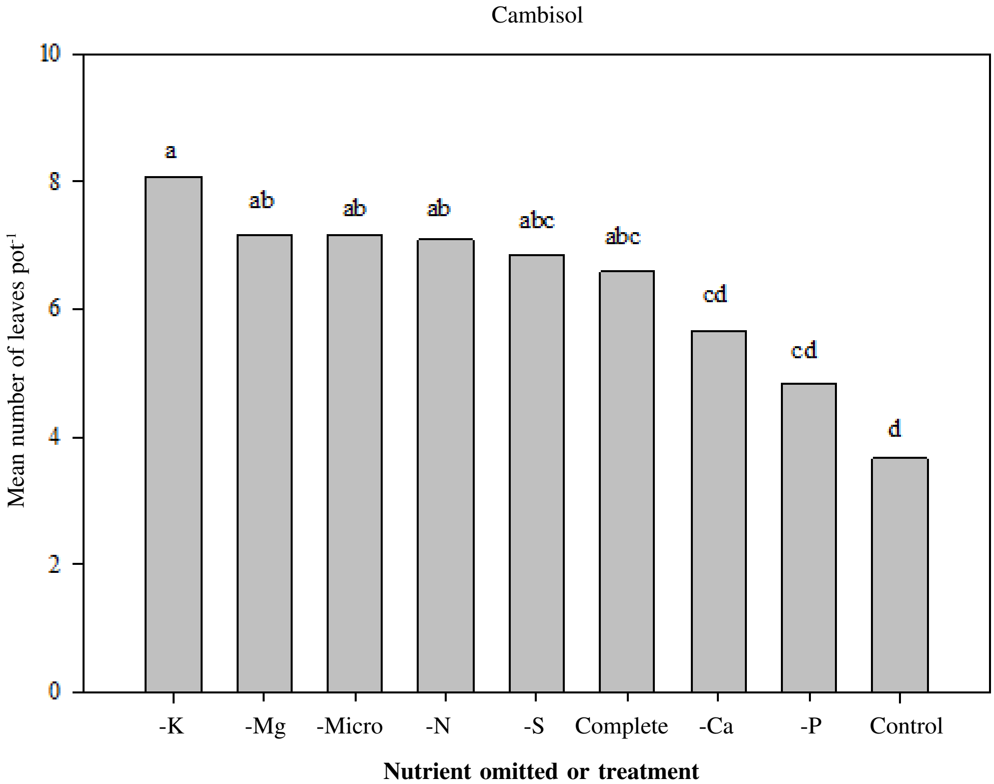

Figure 5. Number of leaves per bean plant grown on a Cambisol in a nutrient omission study.

> 0.05) different from the complete treatment (Fig. 6). Plants grown in the complete nutrient treatment had significantly ($P < 0.05$) more leaves than their counterparts grown in phosphorus and nitrogen omitted treatments. Plants grown in the control had the fewest number of leaves ($P < 0.05$), fewer than the complete treatment, but not significantly ($P > 0.05$) different from phosphorus and nitrogen omitted treatment (Fig. 6). Incidentally, the number of leaves in phosphorus and nitrogen omitted treatments also were not significantly different ($P > 0.05$).

DISCUSSION

Effect of soil type on above ground dry matter production. The accumulation of significantly higher ($P < 0.05$) above ground dry matter in Phaeozem than that from Cambisol and Umbrisol (Fig. 1) could be attributed to differences in nutrient levels. It seems likely that with the low pH values of the Umbrisol and the Cambisol (Table 3) and the high levels of extractable Al, that soil acidity was the main reason for growth differences among the three soils. Phaeozem had greater available P, total N and OM (Table 3) compared to other soils.

In summary, bean growth on the Umbrisol was better than that of the Cambisol, but not as great as that on the Phaeozem soil, documenting that Liddugavu is the better soil for bean production. The results of this nutrient omission study suggest some potential options to improve yields of bean on the Cambisol, and Umbrisol soils.

Effect of nutrient omission on dry matter production in Phaoezem. In Phaoezem soil, bean plants grew the best among the three representative soils, but less growth was

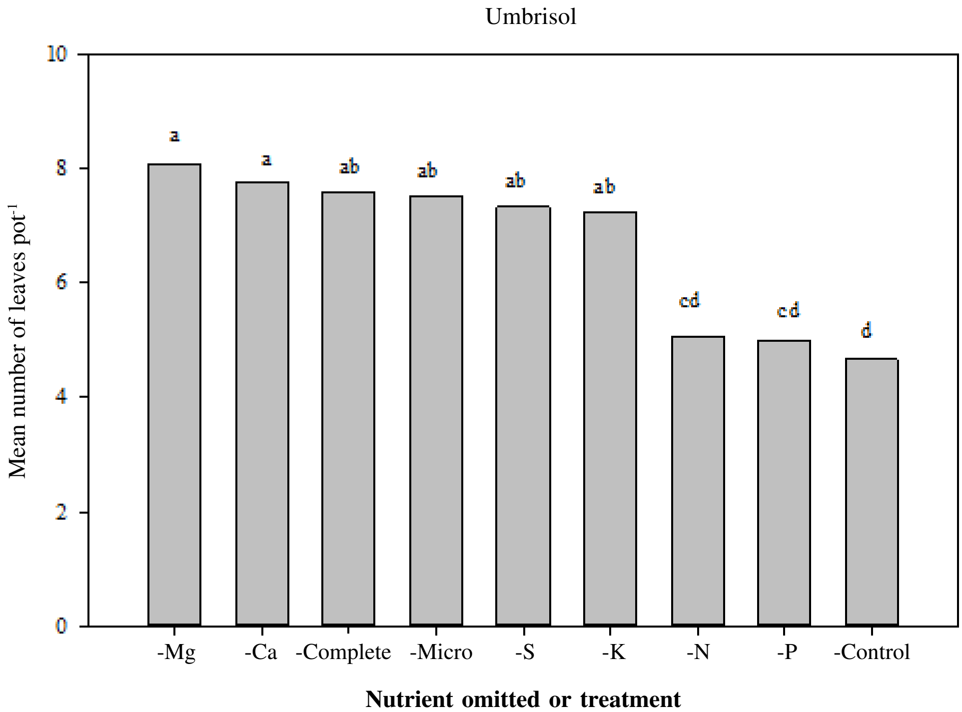

Figure 6. Number of leaves per bean plant grown in an Umbrisol in a nutrient omission study.

observed in the control with no nutrients (Fig. 2). The complete treatment yielded slightly higher above ground dry matter than the N omitted treatment. These results provide scientific data supporting the farmer experience in growing beans on this soil type, where they mentioned that it is the best soil for growing beans.

Effect of nutrient omission on dry matter production in Umbrisol. In distinction with the highly productive Phaoezem soil and the extremely impoverished Cambisol soil; the Umbrisol, yielded intermediate in total bean dry matter production (Fig. 3). The complete treatment had greater above ground dry matter than the N, P and K omitted treatments and the control without any nutrient (Fig. 3), suggesting that these nutrients in particular, were needed for best bean growth. The complete treatment was not significantly ($P > 0.05$) different from all other omission treatments. This can be attributed to the low levels of N, P and K that were below the critical values in Umbrisol (Table 3).

A lingering question is what would the yield have been, had the soil pH been increased with the addition of limestone and the levels of toxic Al reduced (Table 3). We therefore, recommend a follow up study.

The lack of difference among the nutrients other than N, P, K and the control (Fig. 3) might be due to the Law of the Minimum.

The least aboveground dry matter production in the control and phosphorus omitted treatments (Fig. 3) could be attributed to P deficiency. According to Fageria (2006), if P is deficient, plants dependent on N_2 fixation are limited in their production because P is an important element required for N_2 fixation. Maximum benefits from N_2 fixation depend on soil P availability (Kennedy and Cocking, 1997; Graham *et al.,* 2003).

Clearly, nitrogen, phosphorus and potassium were limiting nutrients for bean dry matter production in Umbrisol soil.

Effect of nutrient omission on number of leaves per plant. In Phaeozem, all nutrient omitted treatments and the control treatment were not significantly different from the complete treatment (Fig. 4). This is consistent with what farmers mentioned that this soil type was the best for common bean production. The better performance in this soil could be explained by the inherent fertility of the soil whereby all other nutrients were above the critical value apart from total N and organic matter (Table 3).

Effect of nutrient omission on number of leaves per plant. In Cambisol, beans grown in the complete treatment had significantly ($P < 0.05$) more leaves than did the control without nutrients added (Fig. 5). These results are most likely consistent with the low soil pH and its poor nutrient status (Table 3). This extremely fewer number of bean leaves on this soil without any added nutrient is a sharp reminder of how acid and impoverished this soil is, an observation heard frequently from farmers during the community interviews.

In Umbrisol, bean plants grown in the complete treatment had significantly ($P < 0.05$) more leaves than beans grown in the N and P omitted treatments (Fig. 6), indicating that limited P and N availability were limiting leaf production in the tested soil.

The observation of significantly ($P < 0.05$) fewer number of leaves in the control, P and N omitted treatments (Fig. 6) could be explained by the low levels of these nutrients in the tested soil. The soil was poor in total N and available P right from the begining (Table 3). As a result, growth decreased when N and P were omitted. Results from this study are in conformity with the findings of Hossain and Hamid (2007) in groundnut where plants grown under no application of N and P fertiliser on weathered soils were stunted with fewer and smaller leaves, and poor yield.

CONCLUSION

Phosphorus was the most limiting nutrient for bean production in Umbrisol and this was followed by N and K. In Cambisol, common bean production was most limited by soil acidity. The performance varied with soil types with bean grown on the Phaeozem registering greater leaf number and growth followed by Umbrisol, confirming both local scientist and farmer knowledge that this soil has greater potential than the other two soils.

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