Effect of selected soil amendments on growth and yield of beans in acidic Nitisol of Nyeri County, central Kenya

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Abstract
Common bean (Phaseolus vulgaris L.) is one of the most important grain legumes in Nyeri District. Dry grain yields have remained low (0.22-0.3 t ha⁻¹) due to several biotic and abiotic factors. The main abiotic constraints are deficiency of nitrogen (N), phosphorus (P) and low soil acidity. This study was conducted to determine the effect of one-time application of organic and inorganic soil amendments on the soil pH. The treatments used were lime at 2 t ha⁻¹; Kelphos fertiliser at 375 kg ha⁻¹; diamonium phosphate (DAP) at 200 kg ha⁻¹; manure at 4 ha⁻¹; manure at 4 ha⁻¹+ Kelphos 375 kg ha⁻¹; manure at 4 ha⁻¹+ DAP 200 kg ha⁻¹, lime at 2 t ha⁻¹ + DAP at 200 kg ha⁻¹, lime at 2 t ha⁻¹ + Kelphos at 375 kg ha⁻¹ and control. The experiment was laid out in a randomised complete block design with three replications. The after harvest soil analysis of the topsoil in each of the plots showed increase of soil pH by 0.27 units with lime and kelphos and manure contributing to the highest increase in that order. Above-ground dry biomass yield increased significantly than the control with lime + DAP having the highest yield followed by Kelphos, lime 4.17 and manure at 4.14 ha⁻¹. Dry grain yields increased from 0.66 ha⁻¹ (control) to 1.83 ha⁻¹ (lime + DAP), lime + Kelphos 1.6 ha⁻¹ and manure 1.58 ha⁻¹. Manure gave the highest return to cost of amendment at 558.80% followed by lime with 420.28% and lime + DAP with 251.45%. Manure is recommended as amendment option for production of beans in acidic soils of Nyeri district.

Key words: acid soils, amendments, bean yield.

Introduction
Common bean (Phaseolus vulgaris L.) is one of the most important grain legume that is grown for consumption and accounts for 50% for the grain legume consumed in the world (Wortman et al., 1998). There are 55 known species in the genus Phaseolus and five of these have been domesticated (Broughton et al., 2002). In Kenya and most of eastern and central Africa, common bean is the most important legume. It is commonly grown by small-scale farmers as an intercrop with maize and as a monocrop.

The average annual production of common bean in Kenya stagnant at an average of 0.524 t ha⁻¹ for the last 30 years (FAO, 1997). A six-year production trend (2004-2009) for Nyeri District indicates that the yield remained low at an average of 0.22 t ha⁻¹ for intercrop and 0.30 t ha⁻¹ for monocrop (DAO Nyeri, 2010). Low soil fertility is one of the limiting factors to bean production (FURP, 1994). In central Kenya highlands, continuous cropping without adequate nutrients replenishment is a major cause of low soil fertility (Kanyanjua et al., 2002). Soils in the upper midland zone II and III are also inherently acidic with a pH of 3.4-5.5 (FURP, 1987). Beans are very sensitive to acidity and perform well only at pH 6.0 and 7.0 (FURP, 1994). The major causes of soil acidity in Kenya is high aluminium saturation and Ca and Mg deficiency (FURP 1987), (Kihanda and Gichuru, 1999). Application of lime and other ameliorating materials to raise the soil pH to levels where the crop performance is optimised is an important requirement. When this is done in combination with organic and inorganic fertilisers, there is a large increase in crop yield (Kihanda et al., 2013).

The objectives of the trial was to evaluate the effect of organic and inorganic fertilisers on selected soil chemical properties and growth and yield of beans.
Materials and methods

The experiment was conducted at the Wambugu Agricultural Training Centre (ATC) 0°25 05' and 36°57 E at 1710 m in agroecological zone upper midland II (UM2). The soils are humic nitisols (UNESCO, 1977) well drained, extremely deep, dusky red to dark reddish brown nitisol with friable clay and an acidic humic top soil. The soil pH in water (1:2.5) is 4.8- 5.5 while base saturation is 10-20%. Cation exchange capacity (CEC) is 8-25 Cmol (+) and soil organic carbon is 25-33 t ha (FURP, 1987). The area receives an average annual rainfall of 928 mm while the temperature is 12.9-28.7°C. There are two cropping seasons, March to June (long rains) while the short rains are October to December (Jaetzold et al., 2006). The major agricultural activity is the surrounding area in mixed farming with coffee, dairy and maize production as the major enterprises.

Experimental materials

Agricultural lime. The agricultural lime was sourced from Athi River mining lid and it is a very fine grade product with retention of less than 15% on BSS mesh 100. It is highly soluble with a high acid neutralising value and a bulk density of 1.428-1.72 g / cc contains CaCO₃ (>75%) MgCO₃ (10%), SiO₂ (0.50%).

Kelphos fertiliser. Kelphos is a basal single super phosphate fertiliser which contains 19% P₂O₅ (16% water soluble), 11% Sulfur and 21% CaO.

Cattle manure. The cattle manure used was-well decomposed and was sourced from the ATC’s Zero grazing Unit. It had N = 0.70%, P = 0.36%, K = 1.58%, Ca = 0.79, Mg = 0.06%.

Diamonium phosphate. DAP (18-46-0) is a water soluble ammonium phosphate salt.

Bean variety KTX-56 which is determinate (35-40 cm high), with a potential grain yield of 1.4-1.8 t ha⁻¹ was used as a test crop.

There were nine treatments -- DAP applied at 200 kg ha⁻¹ of the fertiliser, Kelphos (SSP) applied at 375 kg ha⁻¹, Agricultural lime at 2 t ha⁻¹, Cattle manure at 4 t ha⁻¹, Cattle manure at 4t ha⁻¹ plus DAP at 200 kg ha⁻¹, Cattle manure at 4 t ha⁻¹ plus Kelphos at 375 kg ha⁻¹, Agricultural lime at 2 t ha⁻¹ plus DAP at 200 kg ha⁻¹, agricultural lime at 2 t ha⁻¹ plus Kelphos at 375 kg ha⁻¹ and the Control

Agricultural lime was broadcast and incorporated prior to cutting the bean furrows. Kelphos and DAP were drilled on the furrows and incorporated into the soil. Cattle manure was evenly spread on the furrows and thoroughly mixed with the soil. Planting furrows were made based on the recommended spacing of 0.5 m between rows and 0.10 m within the row (one seed per hill) giving a plant population of 200,000 ha⁻¹. All agronomic practices including weeding, insect control and rogouing were carried out as recommended.

The experiment was carried out during the long and the short rains. In both seasons the experiment was laid out as Randomised Complete Block Design (RCBD) with three replications. Data were recorded in the central two rows in an area of 1.0 × 1.5 m².

Select soil chemical analysis were determined at the start and the end of the experiment. These were:

- Soil pH in water (1:25)
- Soil P determined colorimetrically after extraction for 30 minutes and 1:20 w/v soil reagent ratio with 0.5 m NaOHCO₃ and adjusted to pH 8.5 (Anderson and Ingram, 1993)
- Total N in the soil and farmyard manure using the wet acid oxidation method as outlined by Bremner and Mulvaney, (1982).
Data collection and analysis
Data were collected on:

- Soil parameters: these included changes in soil pH, P, N, K. The result on the soil analysis are expressed as a difference between the initial nutrient status at the start and at the end of the experiment.
- Plant parameters included: plant height, flowering percentage, number of pods per plant, no of seeds per pod, above ground biomass and final grain yield.
- Economic analysis was done by first computing the gross margin and finally return to cost of amendment.

Data was analysed using the Statistical Package for Social Scientist (SPSS) soft were version 17.0. Means were separated using Duncan New Multiple range test at 0.05 percent confidence level.

Results and discussion
Soil characteristics
Soil pH.
In all the treatments, except the control and DAP, there was a significant increase in the soil pH within the three months the crop was in the field (Figure 1). Kelphos alone had the lowest increase of the soil pH of 0.25 while lime alone had the highest increase of 0.70. When the treatments were combined, there significant changes in soil pH for example, when lime was used in combination with Kelphos, there was an increase of 0.78 units but the increase in soil pH was significantly (P= 0.05) lower when lime was used in combination with DAP.

![Figure 1: Changes in soil pH](image)

The results indicate that inorganic and organic amendments either alone or in combination can increase the soil pH in one growing season. The main cause of low soil pH was high exchangeable H+ although lime is an excellent source of N and P, it reduces soil pH due to the release of H+ in the soil solution.
Application of lime, Kelphos which is high in CaO is able to neutralise H+ in the soil solution (Okalebo, 2002). The mechanism of manure reducing soil acidity is believed to be through complexation of organic residues with the H+ (Murwira, 1994).

**Soil P.** The initial P in the soil solution was 69 ppm. At the end of the growing season the levels of P in the soil showed marked difference (Figure 2). This was attributed to addition of P to the soil and also plant uptake and fixing or release from the soil matrix. The results showed that after the growing season there were significant (α≤0.05) changes in P levels in all the treatments.

![Figure 2: Changes in P levels as influenced by various treatments](image)

The change in the level of P in plots treated with lime, DAP and manure were not significantly different. Lime, kelphos and manure increased the P by similar amounts while the highest increase in plots that received lime and kelphos. There was increase in P levels upon treatment of the soil with both organic and inorganic amendments when compared to the control. The control reported a decrease which could be attributed to plant uptake. Since Lime did not add P to the soil, the increase in the nutrient can be attributed to release of fixed P as lime increased the soil pH. The plots treated with Kelphos, Lime+DAP, Manure + Kelphos had means that were not significantly different. The means of manure + DAP and Lime + Kelphos were also not significantly different.

This increase could be attributed to release of the fixed P as the pH increased. Similar results were reported by Omenyo et al. (2010). Kelphos added more P to the soil than DAP though DAP has almost double the amount of P. This can be attributed Kelphos having had double effect on the soil. It increased the soil pH thereby increasing solubility of P due to its liming ability and also direct addition of P to the soil. Diamonium phosphate has acidifying effect on the soil and P is fixed at reduced pH. When DAP was used in combination with lime and also in combination with manure it increased P levels significantly similar to what was observed by Ndungu et al. (2003).

**Nitrogen.** The treatments had varied effect on the balance of N in the soil solution (Figure 3). The pre-planting level was 0.172% which was low. Soil total N content decreased in all the plots where the treatments did not add N to the soil. There was no significant (at α≤0.05) difference in N reduction between the control and plots receiving Kelphos and lime. In plots that had N, there was slight increase in N in the topsoil. Manure increased the N level by 0.0240 ppm and DAP by 0.0350, which was the highest. Combination of manure + DAP increased level of N by 0.0263 ppm, manure + Kelphos 0.0282...
ppm and lime + DAP by 0.0333 ppm. The results agree with those of Warren and Kihanda (2001). The means in the plots treated with lime and Kelphos were not significantly different. Likewise, the means of plots treated with manure, manure + DAP and manure + Kelphos were not significantly different.

![Figure 3](image.png)

**Figure 3**: Changes in total nitrogen level as influenced by different treatments

**Potassium levels.** There were generally slight changes in K levels in the soil after harvest (Figure 4). Except for the manure treatments, the rest did not have significant effect on the level of potassium in the soil. There was a slight decrease in plots treated with manure Kelphos (-0.0262 ppm), DAP (-0.0140 ppm), Lime (-0.0222 ppm) and the control (-0.0192 ppm). There was a slight increase in manure plots (0.0344 ppm), manure + Kelphos (0.0370 ppm) and manure + DAP (0.0329 ppm). The three increases were, however, not significantly different.

Soils are generally well supplied in K and it is not a key ingredient in most inorganic fertilisers. However, manure analysis showed an adequate supply of potassium. Potassium is not a critical nutrient for beans since it is not deficient in soil and application of it is not likely to lead to increase in yield.

**Plant height at 45 Days after Sowing (DAS)**

Control, DAP and lime applied alone had significantly lower plant height at 45 DAS than other treatments. Plots treated with kelphos had the longest plants.
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**Figure 4:** Changes in K levels as influenced by various treatments
Figure 5: Height of plants 45 DAS as influenced by various treatments

Yield components
Number of pods per plant. Figure 6 shows the means of the effect various treatments on the number of pods per plant. The control had significantly (p=0.05) the least pods per plant than the rest of the treatments. The control had mean of 8.3 pods per plant compared to a 12.1 and 12.7 for plots treated with manure and lime, respectively. A combination of lime and DAP gave significantly (p=0.05) higher number of pods per plant (16.5) than the rest of the treatments.

![Graph showing number of pods per plant](image)

Figure 6: Number of pods per plant as influenced by various treatments

Biomass yield. The above-ground biomass yield was the total of the vegetative part and grains weight. Figure 7 shows the biomass yield for the various treatments. The control had significantly (p=0.05) lowest biomass yield (2.32 t ha⁻¹) than the other treatments. The highest biomass yield was produced by lime + DAP with 4.4 t ha⁻¹ followed by Kelphos with 4.28 t ha⁻¹, lime with 4.18 and 4.14 t ha⁻¹. Diamonium phosphate had a low yield of 3.2 t ha⁻¹. Plant biomass from plots treated with manure, lime, Lime+Kelphos and Manure+Kelphos were not significantly (p=0.05) different.
Grain yield. All the treatments significantly increased the dry grain yield (Figure ). The lowest grain yield was recorded in the control while the highest yield was in the plots treated with lime + DAP at 1.83 t ha⁻¹. The results are consistent with those obtained by Kihanda (2013). The performance of Lime + DAP was followed by that of lime + Kelphos at 1.65 t ha⁻¹.

Economic analysis. Table 1 shows the gross margin (GM), accruing from the treatments. Lime + DAP had the highest GM (KES 107,990.40) followed by manure (KES 103,522.40) while lime (KES 98,076.60) was third. The control ranks the lowest (KES 47,642.40). Return to cost is calculated by subtracting the GM of the control from the GM of the treatment(s) and dividing this by the cost of the amendment. The result of this shows that Manure alone gave the highest return at 558.80% followed by Lime with...
420.28%, with DAP coming third with 315.9% (Table 2). The high returns from manure and lime were also reported by Kihanda et al. (2013) and Baraza et al. (2010).

**Table 1: Economic analysis**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Treatment levels</th>
<th>Unit cost (KES)</th>
<th>Cost of Treatment</th>
<th>Grain yield (t ha(^{-1}))</th>
<th>Value of yield KES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.6617</td>
<td>47,642</td>
</tr>
<tr>
<td>DAP</td>
<td>200 kg</td>
<td>60.0</td>
<td>12,000</td>
<td>1.3550</td>
<td>97,560</td>
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<td>Kelphos</td>
<td>375 kg</td>
<td>42</td>
<td>15,750</td>
<td>1.4800</td>
<td>106,560</td>
</tr>
<tr>
<td>Manure</td>
<td>4 t</td>
<td>2.50</td>
<td>10,000</td>
<td>1.5767</td>
<td>113,522.40</td>
</tr>
<tr>
<td>Manure + DAP</td>
<td>4 t + 200 kg</td>
<td>62.50</td>
<td>22,000</td>
<td>1.5950</td>
<td>114,840</td>
</tr>
<tr>
<td>Manure + Kelphos</td>
<td>4 t + 375 kg</td>
<td>44.50</td>
<td>25,750</td>
<td>1.5300</td>
<td>110,160</td>
</tr>
<tr>
<td>Lime</td>
<td>2 t</td>
<td>6.0</td>
<td>12,000</td>
<td>1.5283</td>
<td>110,076.60</td>
</tr>
<tr>
<td>Lime + DAP</td>
<td>2 t + 200 kg</td>
<td>66.0</td>
<td>24,000</td>
<td>1.8332</td>
<td>131,990.40</td>
</tr>
<tr>
<td>Lime + Kelphos</td>
<td>2 t + 375 kg</td>
<td>47.0</td>
<td>27,700</td>
<td>1.6467</td>
<td>118,562.40</td>
</tr>
</tbody>
</table>

The price of beans in Nyeri Market (May, 2011) is Kes 6,500 for 90 kg bag

**Table 2: Return to cost of amendment**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Cost of treatment (KES)</th>
<th>GM of treatment (KES)</th>
<th>GM of treatment-GM of control (KES)</th>
<th>% return to investment of the amendment(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>-</td>
<td>47,642.40</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>DAP</td>
<td>12,000</td>
<td>85,560</td>
<td>37,917.60</td>
<td>315.90</td>
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<tr>
<td>Kelphos</td>
<td>15,750</td>
<td>90,810</td>
<td>42,537.60</td>
<td>274.08</td>
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<tr>
<td>Manure</td>
<td>10,000</td>
<td>103,522.40</td>
<td>55,880</td>
<td>558.80</td>
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<tr>
<td>Manure + DAP</td>
<td>22,000</td>
<td>92,840</td>
<td>45,197.60</td>
<td>205.43</td>
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<tr>
<td>Manure + Kelphos</td>
<td>25,750</td>
<td>84,410</td>
<td>36,767.60</td>
<td>142.79</td>
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<tr>
<td>Lime</td>
<td>12,000</td>
<td>98,076.60</td>
<td>50,434.20</td>
<td>420.28</td>
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<td>Lime + DAP</td>
<td>24,000</td>
<td>107,990.40</td>
<td>60,348</td>
<td>251.45</td>
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<tr>
<td>Lime + Kelphos</td>
<td>27,700</td>
<td>90,862.40</td>
<td>43,220</td>
<td>156.0</td>
</tr>
</tbody>
</table>

**Conclusion**

- Lime, Kelphos and manure either alone or in combination raised soil pH by 0.3 to 0.8 units
- Soil amendment with lime, Kelphos and manure improved P availability by 10-20 ppm but changes in total N and K were variable
- The same amendments improved crop growth, crop biomass and final grain yield. The highest grain yield was obtained from plots receiving lime and DAP
- Economic analysis showed that it is profitable to amend acidic soils and the returns to investment puts manure as the best amendment for small-scale farmer.

**Acknowledgement**

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**References**


