# Contribution of Legume Rotations to the Nitrogen Requirements of a Subsequent Maize Crop on a Rhodic Ferralsol in Tanga, Tanzania

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## Abstract

*Industrial fertilizers are expensive for small-scale farmers who, as alternative, rely on legume crops for providing N for a subsequent maize crop. A legume-maize rotational experiment was carried out on a Rhodic Ferralsol at Mlingano Agricultural Research Institute in Muheza, Tanga, Tanzania, to evaluate the effects of legumes rotation in meeting the N fertilizer requirements of maize. The experimental site was located at 39o 52'E, 5o 10'S and 183 metres above sea level (m.a.s.l.). The experiment was conducted for two rotation cycles whereby cowpea, pigeonpea or greengram were grown during the short rains followed by maize during the long rains. The maize rotations were imposed on plots on which legumes had been grown during the previous legume rotation. Monoculture maize was grown with treatments of 0, 25, 50 and 100 kg N ha$^{-1}$ imposed for purposes of plotting N fertilizer response curves. Based on the response curve lines, the effects of the legume rotation on maize yields were compared and translated as N fertilizer equivalency of the legumes in question. The grain and residue yields of the three legumes were significantly different ($P<0.01$), a fact which was attributed to the genetic differences of the legume species. The maize yields following rotation with each of the three legumes were significantly higher ($P<0.05$) than those under continuous maize. The effects of the rotations on increasing the maize yields were equivalent to application of 25, 19 and 16 kg N ha$^{-1}$ for the cowpea, pigeonpea and greengram rotations, respectively. It was, however, concluded that the contributions of N by the legumes in the legume-maize rotations were not enough to satisfy the maize N requirements of 50 kg N/ha; hence supplementation with mineral N, in addition to the rotations, is necessary for increased yields.*

***Key words:*** Legume rotation, fertilizer equivalency, legume residues, maize, relative yield increase.

## Introduction

Legume-cereal rotation is among the most used and sustainable systems of increasing food production under small scale farming (Dakora and Keya, 1997). The sustainability of the system results in from the ability of most legumes to contribute to the soil N budget through symbiotic biological $N_2$ fixation. Thus, legumes can obtain N from the soil and from atmospheric $N_2$ fixation. A part of the plant-accumulated N is harvested in the grain and part is returned to the soil through root excretions, and decomposition of senesced nodules, leaves and other plant residues (Sanginga *et al.,* 2001). Legumes differ in their efficiency with which they channel the fixed $N_2$ to grain, and hence in the quantity of the N returned to the soil for a subsequent crop. Rao and Mathuva (2000), for example, observed higher maize yields under rotation with cowpea than under pigeonpea, which was attributed to differences between the legumes in $N_2$ fixation, and in the quantity and quality of residues between the two legume types.

Cereal crop yield improvements following legume rotations have been reported, and have been attributed both to improvements of the soil N status and other positive rotational effects such as control of weeds and diseases (Bruulsema and Christie, 1987; McVay *et al.,* 1989). Senaratne and Hardson (1988)

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attributed the N benefit to subsequent cereal crops both to sparing of N by the legumes relative to cereals and N carry-over from the legume residues. An N sparing of up to 31 kg N $ha^{-1}$ has been reported (Patra *et al.,* 1987; Bowen *et al.*, 1988; Dakora and Keya, 1997). However, the N sparing was not observed by Keating *et al.* (1988) and Evans et al. (1991) under cowpea-maize rotation. On the other hand, MacColl (1989) observed increased maize yields resulting in from mineralization of cowpea roots and nodules. Increase in cereal yields after legumes rotation has further been attributed to changes in microbial activities (Turco *et al.,* 1990) and to both early availability of N and early infection of maize roots by versicular arbuscular mycorrhizae, which increased P availability and enhanced uptake of micronutrients such as copper and zinc (Johnson *et al.,* 1992; Bagayoko *et al.,* 2000). Reduction in pigeonpea fusarium wilt infestation has been reported under pigeonpea-maize rotation as compared to that under pigeonpea monocrop (Rao and Mathuva, 2000). Cowpea rotation was reported to contribute to the maize N requirement the equivalent of 60 kg N $ha^{-1}$ (Dakora *et al.*, 1987), 80 kg N (Mughogho *et al.,* 1982), 45 kg N (Adetunji, 1996), and 32 kg N $ha^{-1}$ (Bloem and Barnard, 2001). The contribution of pigeonpea rotation was reported to be equivalent to application of 70 kg N $ha^{-1}$ (Peoples and Herridge, 1990).

Legume-maize rotation is a common practice under small-scale maize production in Muheza district, Tanzania. The crops are grown on Ferralsols low in plant nutrients, particularly N. The legumes mostly used include cowpea, pigeonpea and greengram, which are grown without application of mineral N fertilizer during short rains, followed by maize during long rains, again without application of N fertilizer. The maize stover is usually used for livestock feeding, further taking away N from the soil. Although legume rotations are included, the maize yields in the subsequent maize rotations are generally much lower than the yield potentials of the maize varieties. This necessitated an investigation aimed at determining the contribution of the legume rotations to the N nutrition of the succeeding maize crop. An additional objective of the study was also to get an insight into the amount of mineral N fertilizer required to be supplemented to obtain higher maize yields in the legume-maize rotational cropping system.

## Materials and methods

This study was carried out on a Rhodic Ferralsol at Mlingano Agricultural Research Institute in Muheza district, Tanga region, Tanzania, located at 39°52'E, 5°10'S and 183 m.a.s.l. The site is characterized by a bimodal rainfall pattern with long rains of about 600mm between March and June and short rains of about 350 mm between October and December. The maize (Zea mays, L., variety TMV-1) rotation was during the long rain seasons, while the legumes, namely cowpea (Vigna unguiculata, L. Walp, variety Vuli-1), pigeonpea (Cajanus cajan, L. Millsp, variety Komboa) and greengram (Vigna radiata, L. Wilezek, variety Imara) rotations were during short rain seasons. Before laying out the experiment, the fertility status of the site was characterized based on a composite soil sampled from the 0 – 20 cm depth, which was air-dried, sieved through a 2 mm screen and analysed for some chemical and physical parameters. Particle size distribution was determined using the Bouyocos hydrometer method (Dewis and Freitas, 1970). The pH was determined in the 1:2.5 soil extract ratio in water and in 1.0 M KCl ( McLean, 1965); organic carbon by Walkley-Black wet oxidation (Nelson and Sommers, 1982); total N by micro-Kjeldahl (Bremner, 1965); extractable P by Bray-1 procedure (Bray and Kurtz, 1945); CEC by saturation with 1.0 M ammonium acetate (Chapman, 1965); and Ca and Mg, and Na and K by atomic absorption spectrophotometry and flame photometer, respectively, from the ammonium acetate filtrates. The chemical and physical characteristics of the experimental soil are presented in Table 1. The textural class of the soil was sandy clay. According to Landon (1991), the experimental soil's reaction was medium acid, which is suitable for most annual crops. The total N was very low, indicating a need for external N input for high maize yields, but the low N level offers suitable condition for atmospheric $N_2$ fixation by legumes. The organic carbon was low, whereas the C: N ratio indicated presence of a good quality soil organic matter. The site had low available P, necessitating application of the recommended rates of P fertilizer to both maize and legumes. The exchangeable Ca was low whereas the exchangeable K and Mg were medium.

**Table 1: Some physical and chemical characteristics of the surface soil (0 – 20 cm) of the experimental site**

| Parameter (+ units) | Value |
|---|---|
| Clay (%) | 48 |
| Silt (%) | 10 |
| Sand (%) | 42 |
| pH (H2O) | 5.6 |
| Organic carbon (%) | 1.22 |
| Total N (%) | 0.09 |
| Bray -1 P (mgkg-1) | 3 |
| CEC (cmol+kg-1) | 6.33 |
| Exchangeable Ca (cmol+kg-1 ) | 2.0 |
| Exchangeable Mg (cmol+kg-1) | 0.5 |
| Exchangeable K (cmol+kg-1 ) | 1.02 |
| Exchangeable Na (cmol+kg-1) | 0.15 |
| Base saturation (%) | 58 |

The experimental design was a randomized complete block with four replications. The treatments during legumes rotations included the three legumes and a no-crop control plot, and all plots (cropped and not cropped) were maintained weed-free by weeding operations. During the maize rotation, the maize treatments were imposed onto the plots onto which the legumes had been previously grown during the legume rotations, the control plots (which had no crop in the previous rotation), and continuous monocrop maize plots which received urea [CO(NH2)2] fertilizer at 0, 25, 50 or 100 kg N $ha^{-1}$. The gross plot sizes were 5 m x 5 m, and the net plots were 3.5 m x 3.6 m and 3.75 m x 3.6 m for the legumes and maize, respectively. The legumes and maize were grown based on the recommended plant spacings and densities which were 50 x 20 cm (2 plants per hill) for the cowpea and pigeonpea, while the greengram was 50 x 10 cm (2 plants per hill). The maize spacing was 75 x 30 cm (1 plant per hill). Triple superphosphate [Ca (H2PO4)2] fertilizer was basal-applied during both legumes and maize planting, at the rate of 30 kg P $ha^{-1}$. No N fertilizer was applied to the legume or maize plots earmarked for the rotation treatments. Urea was applied to respective treatments in splits; one third at planting and two thirds top-dressed 28 days after emergence. At maturity, legumes pods were harvested, threshed and weights of the grain recorded on air dry basis. The aboveground residues (including pigeonpea litter fall) were weighed and returned to the plots. The N content and oven-dry weights of the applied residues were determined based on sub-samples of the residues. The determination of the plant N contents was according to Bremner (1965). The maize cobs were harvested, shelled and the grain weighed at 12 % moisture content. The stover was removed from the plots.

The maize grain yields of the treatments under rotation were subjected to analysis of variance using the MSTAT-C statistical package to determine the treatment effects using the F distribution, whereas the yields from the mineral N-fertilized treatments were used to plot N fertilizer response curves to obtain the fertilizer equivalent values of the legumes in question.

## Results and discussion

### Crop yields under the rotations

The legume and maize grain yields, and the above ground legume residue yields, are presented in Table 2. The legume grain and residue yields were significantly different at P<0.01 and 0.001, respectively, between the three legume species. The highest grain yield was that of cowpea and least was from the pigeonpea, whereas the highest residue yield was from cowpea and least from greengram. The differences in the quantities of the grain and the residues yields among the legumes could be explained by the genetic characteristics of individual legume and difference in their plant population the densities.

**Table 2: Mean legumes grain and residues, and maize grain yields**

| | Legume | | Maize |
|---|---|---|---|
| Treatment | grain, | residue, | grain, |
| | $kgha^{-1}$ | kg $Nha^{-1}$ | $kgha^{-1}$ |
| Cowpea - maize | 1158a | 2110a | 660a |
| Pigeonpea - maize | 538c | 1743b | 642a |
| Greengram - maize | 889b | 1359c | 583a |
| Continuous maize (Control) | - | - | 343b |
| F – test | ** | *** | * |
| CV % | 16.9 | 12.5 | 22.6 |

Means followed by the same letter within the column are not statistically different according to Duncan's New Multiple Range Test
*, ** and *** indicate significant differences at P = 0.5, 0.01 and 0.001, respectively

The maize grain yields were lower than the potential yield (3.5 t $ha^{-1}$) of the TMV-1 maize variety at the site when mineral N fertilizer is applied. This was attributed to soil moisture stress which prevailed towards tasselling. The maize yields under the legumes rotation, however, were significantly higher ($P<0.05$) than that of continuous maize, with relative increases of 92, 89 and 70 % under the cowpea, pigeonpea and greengram rotations, respectively. However, there were no significant differences in maize grain yields among the three legumes in rotation. The higher maize grain yields in plots where the legumes were grown in rotation than that under continuous maize cropping could be attributed to the contribution of N by the legumes when they were rotated with maize. The effects could partly be associated with the above-ground residues returned to the plots after harvesting the legumes.

**Contents of N the legume residues**

The quantities of N contained in the above-ground legume residues and the amounts of the residue-N derived from $N_2$ fixation are shown in Table 3. The N concentrations in the above ground residues were between a maximum of 1.72% (for cowpea) and 1.46% (for greengram). The respective total N returned to the soil through incorporation of the above ground residues were 36.3 and 19.8 kg N $ha^{-1}$. Based on an experiment carried out parallel with the rotational experiment to study the $N_2$ fixation ability of the legumes (Marandu, 2005), the legumes fixed less than 50 % of their N requirements. Out of the total N contained in the residues, therefore, the amount which was derived from N2 fixation was equal to or less than 14.5 kg N $ha^{-1}$. The quantities of the residues' N derived from N2 fixation indicate the contribution of the legumes to the soil N pool and, hence, or the advantage of growing the legumes in rotation with maize. Legumes obtain part of their N requirements from the soil and the rest from $N_2$ fixation. In so doing, some of the soil N is spared. A maize crop grown in rotation will, therefore, benefit both from the quantities of N returned to the soil with the legume residues, and the N spared by the legumes. Sustainability of a legume-maize rotation cropping system, therefore, will depend on the net effect between the quantities of nutrients removed or returned to the fields (soils). Comparing the three legumes, the quantity of fixed N contained in the above ground cowpea residues was about two-fold that of the greengram or pigeonpea residues. This indicates that cowpea is superior to either the greengram or pigeonpea in soil N replenishment. The differences among legumes could be explained by their genetic characteristics. Legumes partition to the grain and residues the N they accumulate during growth. Legumes with low-N harvest index translocate little amount of the absorbed and the fixed N2 to the grain, leading to high-N residues. A low-N harvest index has been reported for cowpea (MacColl, 1989; Peoples and Graswel, 1992). Such legumes with a low-N harvest index lead to a net higher gain of N in the soil in the cropping system (Jeranyama *et al.*, 2000).

**Table 3: Quantities of N in legume residues and amounts of N added to the soil through $N_2$ fixation**

| Treatment | Residues, kg ha-1 | N content, % | Total N, kg ha-1 | % of N fixed# | Residues' N fixed, kg ha-1 |
|---|---|---|---|---|---|
| Cowpea | 2110 | 1.72 | 36.3 | 40 | 14.5 |
| Pigeonpea | 1743 | 1.48 | 25.8 | 25 | 6.5 |
| Greengram | 1359 | 1.46 | 19.8 | 39 | 7.7 |

The observed increase in maize grain yields under the legume-maize rotations could also be attributed in part to the nutrients released from the legume roots and nodules. Nitrogen released from these sources was reported to have a significant contribution to increased maize yields (Bloem and Barnard, 2001). Although the quantities of the roots and nodules in the current study were not quantified, their contribution to the increased maize grain yield cannot be neglected or ruled out. The higher maize grain yield could also be attributed to the N sparing effects of rotations, as was observed by Patra *et al.* (1987), Bowen *et al.* (1988) and Dakora and Keya (1997), as well as to the breaking of cycles of pests in component crops within the rotation (Bagayoko *et al.,* 2000; Rao and Mathuva, 2000). These additional rotational effects were, however, not determined in the current study.

The effects of the legumes rotation on the maize grain yields were estimated using the maize grain yield response curve plotted using the data from the mineral-N fertilized treatments (Figure 1). Based on the response curve, the effects of the legume rotations on maize grain yields, translated as fertilizer equivalents (FEQs), were 25 kg N $ha^{-1}$ for the cowpea, 19 kg N for the pigeon pea and 16 kg N $ha^{-1}$ for the greengram rotations. Differences in the potential of the legumes in improving subsequent maize yields have also been reported in the literature. Rao and Mathuva (2000), for example, observed higher maize yields under rotation with cowpea than with pigeonpea, which was attributed to differences between the legumes in $N_2$ fixation capacity, and quantity and quality of residues. Similar effects were reported by Adetunji (1996) on maize-cowpea rotation on an Oxic Paleudult. The relative maize grain increase of 89% under the pigeonpea rotation in this study was similar to that reported by MacColl (1989) in Malawi. The fertilizer equivalency in the study of MacColl (1989) was 67 kg N $ha^{-1}$ , which is higher than the 19 kg N $ha^{-1}$ in the current study. However, the findings by MacColl (1989) were based on two years of continuous pigeonpea cropping before the maize rotation. The two years of pigeonpea monocropping could have increased the N fertility build-up on the experimental plots. The lower N build-up presently could explain the lower fertilizer equivalency value obtained in this study, which was based on one year (season) of monocropped pigeonpea before the maize rotation.

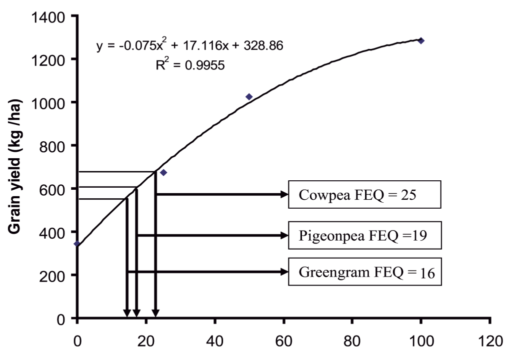


**Figure 1: Response of maize to fertilizer application in terms of grain yield**

## Conclusion

Growing of the legumes in rotation with maize contributed to the N requirements of the maize. The maize yields following the legume rotations were equivalent to those following application of 25, 19 and 16 kg N $ha^{-1}$ in the case of the cowpea, pigeonpea and greengram, respectively. These equivalencies of N fertilizer are less than the 50 kg N $ha^{-1}$ recommended for continuous maize production at the study area. It is necessary, therefore, that maize in such cropping system be supplemented with mineral N fertilizer, in addition to rotations, to optimize the maize yields.

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