Potential of Cowpea, Pigeonpea and Greengram to Supply Mineral N to Maize in Rotation on Ferralsols in Muheza Tanga- Tanzania

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Abstract

A rotational field experiment of cowpea, pigeonpea and greengram with maize as married out for two rotational cycles to determine the potential of the legumes to supply N to the subsequent maize. The experiment was carried out on sandy clay Rhodic Ferralsol with bimodal rainfall pattern. The legumes were planted during the short rain season followed by maize during long rains. Soil was sampled from 0 – 20 cm layer before maize planting from plots where the legumes were grown and from continuous maize plots. The composite soil samples were sieved through 6 mm screen while fresh. Sub samples equivalent to 250 g each were incubated in 500 ml wide mouth volumetric flasks at 60% field capacity and room temperature for 42 days. Destructive samplings were done at 14 days intervals and analysed for mineral N (NH_4^+ and NO_3^-). The quantities of mineral N increased with incubation time. Most of the mineral N was mineralised between 0 and 14 days of incubation. Out of the total N mineralized during the entire incubation period, the proportions of the mineral N determined at the 14th day sampling were 64% for the cowpea, 50% for the pigeonpea, 73% for the greengram and 88% for the continuous maize plots. Such high proportions indicate that the subsequent maize would obtain maximum N during these early stages of growth. It was concluded that there is lack of synchrony between the release of mineral N and the maize crops' N demand which lead to the maize N deficiency symptoms and low yields observed in the legume – maize_cropping system.

Keywords: Aerobic mineralization, incubation, legumes, rotation

Introduction

Nitrogen is one of the major elements required by plants for growth and production. However it is depleted in most soils in Sub- Sahara Africa (SSA), to a level that adversely affects soil productivity (Bationo, 2003). This is evident from nutrient balance studies from 38 SSA countries (Stoorvogel and Smaling, 1990; Stoorvogel *et al.*, 1993), which show that the average N balance is –22 kg ha^{-1} year^{-1}, of which Tanzania accounts for –27 kg ha^{-1} year $^{-1}$ (Stoorvogel *et al.*, 1993).

Continuous cropping without appropriate land management practices and addition of nutrients to the soils to replenish those taken up and harvested with crops is the primary cause of the negative nutrient balance (Smaling *et al.*, 1997; CP-URT, 2000). Possible strategies to alleviate this trend of declining N in agricultural

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soil under small-scale farming include use of low cost technologies such asgrain legumes in rotations with cereals (Dakora and Keya, 1997). Such rotations take the advantage of the legumes contributions to the soil N budget through N_2 fixation (Sanginga *et al.*, 2001). Increased cereal crop yields following such rotation has been reported in many studies (MacColl, 1989; Adetunji, 1996; Rao and Mathuva, 2000; Bloem and Barnard, 2001).

The increased cereal yield has been associated with effects such as improvement of soil physical properties (Rao and Mathuva, 2000), improved microbial activities (Turco *et al.*, 1990; Johnson *et al.*, 1992; Bagayoko *et al.*, 2000), interruption of pests and disease cycles, (Sanford and Hairstron, 1984; MacColl, 1989; McSorley *et al.*, 1994; Bagayoko *et al.*, 2000; Rao and Mathuva, 2000) and early versicular arbuscular mycorrhizae infection which increases P availability and enhances uptake of micronutrients such as copper and zinc (Dodd *et al.*, 1990; George *et al.*, 1994; Ortas *et al.*, 1996).

The contribution of grain legumes to cereal N requirement is often associated with the N_2 fixation ability of the legumes. The legumes take less amount of soil N compared to cereals there by sparing some N to subsequent cereal. Furthermore, the above and below ground residues upon decomposition release NO_3^- and NH_4^+ forms which are absorbed by the cereal crop. Part of the N mineralized from residues returned to the soil was absorbed from the soil while some were fixed from the atmospheric N_2 by the legumes. To make optimum advantage of the mineralized N in legume – maize rotation cropping system, the release of this nutrient from residues should be in synchrony with the maize crop demand.

In Muheza District in Tanzania, small-scale farmers often grow cowpea, pigeonpea, or greengram in rotation with maize. The maize yields however, are usually lower than what would be expected under continuous cropping with mineral N fertilizer. This necessitates an investigation on the legumes' contribution to the maize N nutrition. This paper presents results of an incubation experiment of N mineralization of soil sampled from a field at the time of maize planting where the cowpea, pigeonpea and greengram were grown in rotation with maize for two rotational cycles to assess the potential of the legumes to supply mineral N to subsequent maize crop.

Materials and methods

Legumes- maize rotational experiment was carried out for two rotational cycles at Mlingano Agricultural Research Institute in Muheza district, Tanzania located at 39° 52′E and 5° 10′S with an altitude of 183 m.a.s.l. The area is characterized by a bimodal rainfall pattern with long and short rain seasons, which fall between March and June, and between October and December, respectively.

The field experiment was a randomized complete block design with four replications. Before the start of the rotational cycles, site characterization was done by analyzing some physical and chemical characteristics of a composite top soil sampled at 0 -20 cm depth.

(i) Short rain season

The rotation started with legumes which were grown during short rainy seasons. The treatments included three legumes; cowpea, [*Vigna unguiculata* (L) Walp*)*], pigeonpea [*Cajanus cajan* (L) Millsp)] (a short duration variety), and greengram (*Vigna radiata* (L) Wilezek*)*] and continuous maize (Variety TMV-1) was a control. The continuous maize plots were not cropped during the legume phase of the rotation but were maintained weed free by hand hoe during weeding operations of the legumes. The weeded weeds were left on the plots to decompose. No N fertilizer was applied but triple superphosphate (TSP) was basal - applied to legumes plots at the rate of 30 kg P ha^{-1}.

At maturity the legume pods were harvested and the above ground residues weighed and returned to the plots and subsamples analysed for total N.

(ii) Long rain season

During the long rainy seasons, maize (*Zea mays)* was planted in plots where the legumes were grown and that of continuous maize. Mineral N fertilizer was not applied, but TSP was applied at the rate of 30 kg P ha^{-1}.

At maturity, the maize cobs were harvested, and the stover removed from the plots.

At the time of maize planting soil was sampled from 0 – 20 cm layer in plots by shovel. The soils from the same treatments in the four replications were composited to constitute one sample per treatment. The composite samples were sieved while fresh to pass through 6 mm screen. A fresh soil sample, equivalent to 250 g oven dry basis was incubated in wide mouth 500 ml volumetric flasks (in triplicates) in a greenhouse at 60% of field capacity moisture content for 42 days. Destructive sampling was done at 14 day intervals. The soil in the flasks to be sampled was thoroughly mixed before sampling for determination of mineral N as following. Ten gram portions of fresh soil were weighed into plastic bottles, and 100 ml of 2M KCl were added and shaken in a horizontal position on a shaker for 1 hour. The suspensions were filtered through pre - washed Whatman no. 42 filter paper. Ammonium N (NH_4^+ - N) and nitrate N (NO_3^- - N) were determined from the filtrates by steam distillation method according to Okalebo *et al.* (1993).

Results and discussions

(a) Site characterization

The chemical and physical characteristics of the field experimental site are presented in Table 1. The soil is classified as Rhodic Ferralsol. According to Landon (1991), the soils' reaction was medium acid. The total N was very low, indicating a need for external N input for high maize yields, but a suitable condition for the legumes to fix atmospheric N_2. 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 external P fertilizer application for effective legumes nodulation and high maize yields. Triple super phosphate fertilizer was therefore applied at recommended rate for the site to both the legumes and maize during rotation. The exchangeable K and Mg were medium whereas the exchangeable Ca and CEC were low.

Table1: Physical and chemical characteristics of the experimental soil

Parameter	Value
Clay (%)	48
Silt (%)	10
Sand (%)	42
pH (H_2O)	5.6
Organic Carbon (%)	1.22
Total N (%)	0.09
C/N	13
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

(b) Incubation experiment

The average quantities of cumulative mineral N of incubated soils for the two seasons are presented in Table 2. The quantities of mineral N increased with incubation time. This could be attributed to increased microbial activities as a result of increased moisture content to the 60% field capacity of the incubated soil. At the 14 days sampling, the mineral N of the cowpea and greengram were significantly higher (P= 0.01) than that of the pigeonpea and continuous maize treatments, whereas that of pigeonpea and continuous maize were not statistically different (P = 0.001).

The significant lower mineral N of the pigeonpea relative to those of cowpea and greengram could be attributed to the late incorporation of the pigeonpea litter, which was incorporated in February after grain harvesting, whereas those of cowpea and greengram were harvested in December and residues left on the plots.

Table 2: Cumulative (mean 2003 and 2004) mineral N of incubated soil before maize planting

Treatment	SAMPLING INTERVAL (DAYS)			
	0	14	28	42
	..mg	kg^{-1} ...		
Cowpea – maize	23.5	40.8^a	52.3^a	63.9^a
Pigeonpea – maize	21.1	31.4^b	46.4^b	63.4^a
Greengram – maize	22.4	39.8^a	48.8^{ab}	54.6^b
Continuous maize (control)	20.4	34.3^b	34.4^c	39.0^c
F- test	Ns	**	***	***
C V%		6.7	5.9	3.9

Means within the same column with same superscript are not significant different according to Duncans New Multiple Range Test
, and * indicate significant difference at P = 0.01 and 0.001, respectively
Ns indicate not statistically analysed

The latter two residues therefore, were at advanced stage of mineralization compared to that of pigeonpea. At this time of sampling, the pigeonpea litter was still immobilizing soil mineral N as indicated by slightly lower mineral N values compared to that of continuous maize i.e. the control. The significant higher mineral N of the cowpea and greengram compared to that of continuous maize therefore indicate contribution of the legumes to mineral N at this time of sampling.

At 28th and 42nd days sampling the quantities of mineral N from the plots where the legumes were grown were significantly higher (P= 0.001) than the continuous maize which indicate the significant contribution of the legumes in rotation to increase mineral N supply to the subsequent maize. The differences in quantities of mineral N among the legumes could be attributed to differences in quantities of above ground residues applied (Table 3). The three legumes are also genetically different and hence their N_2 fixing potential, which influences the quantities of total N returned to the soil in both the above and below ground residues.

Table 3: Legume aboveground residues, the N content and the N returned to the soil

Legume	Residue	N content	Total N added
	(kg ha^{-1})	(%)	(kg ha^{-1})
Cowpea	2110^{a}	1.72	36.3
Pigeonpea	1743^{b}	1.48	25.7
Greengram	1359^{c}	1.46	19.8
F test	***	Ns	Ns
Cv%	2.5		

Means within the same column with same superscript are not significantly different according to Duncans New Multiple Range Test
*** indicate significant difference at P = 0.001
Ns indicate not statistically analysed

The proportions of the mineral N determined at the 14th day of incubation with reference to that at the 42nd day were 64% for cowpea, 50% for the pigeonpea, 73% for the greengram and 88% for the continuous maize plots.

Such high proportions of mineralized N are of practical importance when considering availability of the released mineral N to the subsequent maize in rotation. At 14th day after maize planting, the maize plants are at a very young stage of growth coupled with low mineral N demand. Usually this period coincides with relatively heavy rains which subject the mineralized N (large proportion of which is NO_3^- form) to leaching and become unavailable to the maize crop. Increased maize N demand coincides with low mineral N releases from the native soil organic matter and/or the legumes' residues.

The quantities of mineral N at 42nd day for soils from the cowpea, pigeonpea or greengram plots in rotation with corresponding amounts per hectare are presented in Table 4. The data reflects the quantities of mineral N, which could be contributed by the three legumes during the active growing period (when the maize crop is about to tassel), assuming soil moisture is not limiting and various losses of different forms of N are controlled. Theoretically substantial quantities of mineral N are supplied by the legumes to the subsequent maize crop. In the study area, a rate of 50 kg N ha^{-1} is recommended to be applied to monocropped maize for optimum economic yield (Mowo *et al.*, 1993). Except for the greengram, the mineral N released following cowpea and pigeonpea rotation could be enough to support the maize crop. Unfortunately, this is not the case due to lack of synchrony between mineralization and maize crop N demand. As pointed out above most of this mineral N is released in the first 14 days when the maize plants' N demand is low posing possibility of most of the mineralized N getting lost through leaching.

Table 4: Mineral N at 42nd day of incubation and corresponding values on hectare basis

Treatment	Mineral N	Net N*	N equivalent#
	…. mg	kg ….	$Kgha^{-1}$
Cowpea - maize	63.9	24.9	54.8
Pigeonpea – maize	63.4	23.3	53.7
Greengram – maize	54.6	15.6	34.3
Continuous maize (control)	39.0	NA	NA

*Net N is the difference between mineral N of treatments in rotation and continuous maze (Control) # Equivalent N ha^{-1} was obtained by converting the net N on hectare using 2.2×10^6 kg of furrow slice soil;
NA = not applicable (mineral N was the reference)

The increase in maize plants' N demand as the plants grow coincides with little mineral N release, leading eventually to inadequate N supply to the maize plants. This could account for the lower maize grain yields usually obtained in fields in the study area when the legumes are rotated with maize compared to that under continuous maize cropping with application of the recommended 50 kg N ha^{-1}.

The potentials of soils to supply mineral N under aerobic mineralization are also reported in various incubation studies. Horst and Hardter (1994), for example, observed that net N mineralization after 42 days of incubation of topsoil sampled from plots previously grown with cowpea in rotation with maize was higher by 33% as compared to that from maize monocropped plots. The study by Horst and Hardter (1994), however, was of soil sampled from 0 – 30 cm, air dried and sieved through 2mm before incubation (as compared to 6mm in the present study). The deeper soil sampling accompanied by the finer grinding and sieving might have eliminated a substantial quantity of organic matter, whereas air-drying of the samples before incubation might have killed some of the microorganisms. In the current study, the soil was sampled from 0 – 20 cm depth and sieved through 6 mm screen, then incubated while fresh. In so doing the soil microbial environment was less disturbed. This could account for the relatively higher mineral N obtained in the current study.

Conclusion

Mineral N released to the soil following the three legumes' rotation with maize could be substantial to support subsequent maize in rotation. Most of the mineral N is released two weeks after planting, therefore not in synchrony with the maize plants' demand. This necessitate the need for the top dressing of N fertilizer towards maize tasselling to supplement N released from mineralization of legume residues and that from soil organic matter.

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