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Effect of Organic and Inorganic Nutrient Sources on Soil Mineral Nitrogen and Maize Yields in Western Kenya

Ayuke, F.O.[1,4*], Rao, M.R.[2,3*], Swift, M.J.[4] and Opondo-Mbai, M.L.[1]

[1]Department of Forestry, Moi University, P.O. Box 1125, Eldoret, Kenya
[2]International Centre for Research in Agroforestry, P.O. Box 30677, Nairobi, Kenya
[3]ICRISAT Colony (plot II, phase 1), Secunderabad-500 009, Andhra Pradesh, India
[4]Tropical Soil Biology and Fertility Programme, Institute of CIAT, P.O. Box 30677, Nairobi, Kenya

*Corresponding address: P.O. Box 30677, Nairobi, Tel. 524000, Ext 4771, Email: Fayuke2002@yahoo.co.uk; Fayuke@cgiar.org

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Abstract

The effects of organic and inorganic fertilizers on soil mineral N and maize yields were evaluated in a Kandiudalfic Eutrodox soil of western Kenya.

Leaf biomass of tithonia (*Tithonia diversifolia* [Hemseley] A. Grey) and senna (*Senna spectabilis* D.C. & H.S. Irwin) at 5 t ha^{-1} dry weight were incorporated into the soil and compared with the response obtained from control without any input and fertilizer at 120 kg N, 150 kg P and 100 kg K ha^{-1} from urea and triple super phosphate (TSP). Soil mineral (inorganic), N, was measured at the beginning of the trial and subsequently at 1, 2, 4, 8 and 12 weeks after applying the treatments. Maize grain and stover yields were estimated at harvest.

Total inorganic nitrogen in the soil at the beginning of the season was at a similar level in all treatments. It increased rapidly after applying the materials and at the onset of rains for all treatments probably because of rapid nitrogen mineralisation in all treatments. After four weeks, inorganic nitrogen decreased progressively until end of the experiment in all the treatments. The highest contribution of mineral N to the soil by the organic residues was noted at four weeks stage and this was significantly higher with tithonia than senna. This could be due to rapid N mineralization by these residues. Senna treatment that had the lowest mineral N during the first weeks of the trial, showed that N mineralization was slow with the mineral N reaching highest level at four-week stage. However, it is interesting to note that while soil N under tithonia was statistically higher than in senna at four weeks, it was higher under senna at later stage observations. Thus tithonia decomposed completely in about four weeks, while senna was still mineralizing at 8 weeks.

Fertilizer use increased maize grain yield by 63% over the control. Although tithonia biomass increased maize grain yield by 38% over the control and did not differ significantly from fertilizer treatment, senna increased maize yield by only 6% over the no input control. Higher yield with tithonia than senna was partly because of higher nutrient concentration and hence greater amounts of nutrients added for the same quantity of material applied. The study indicates that high quality residues such as tithonia can be used as sources of nutrients to improve crop yields.

Keywords: Biomass transfer, *Tithonia diversifolia, Senna spectabilis*, mineral nitrogen, maize yield.

Introduction

Crop yields in large parts of Kenya are low due to declining soil fertility as a result of continuous cropping and non-application of fertilizers by farmers. For example, soils in western Kenya, (Acrisols, Ferralsols and Nitisols)(FAO, 1965) are poor in organic matter content and have low reserves of nitrogen (N), phosphorus (P) and some trace elements

(ICRAF, 1994; ICRAF, 1997; Mwiinga *et al.*, 1994; Mugendi, 1996; Sanchez *et al.*, 1997; Rao *et al.*, 1998). In addition they are easily compacted and are prone to erosion. As soon as the vegetative cover is removed and land intensely cropped with grain crops, the soil's physical, chemical and biological properties are readily degraded (ICRAF, 1993; Sanchez *et al.*, 1997).

With the liberalization of trade and introduction of structural adjustment programmes (SAP), fertilizer costs have increased to a level unaffordable to small-scale farmers. How to increase and maintain crop yields to meet the needs of the growing population has become a major national problem. Agroforestry technologies such as short duration planted tree fallows and green manuring (biomass transfer) with tree residues have been demonstrated to increase crop yields (Niang et al., 1996; ICRAF, 1997). These technologies have also been found to be economically attractive to farmers (Sanchez et al., 1997). In the absence of fertilizers, crop production relies largely on nutrient management through organic residues (Vanlauwe et al., 1996; Rao *et al.*, 1998).

In western Kenya, farmers have live fences around their farms and grow shrub and tree hedges on contours, but rarely use the biomass from these trees and shrubs for soil fertility improvement. Several studies have shown that tree residues can be used as a source of nutrients to crops (Niang *et al.,* 1996; Palm, 1996; ICRAF, 1997). The residues serve mainly as source of organic matter and nitrogen, but may also contribute significant amounts of other essential nutrients. These residues upon incorporation into the soil can help increase crop yields. For example, experiments conducted in western Kenya, have demonstrated that higher yields can be obtained with leaf biomass of *Tithonia diversifolia* (Hemsley) A. Gray than even with commercial urea fertilizer (ICRAF, 1996; ICRAF, 1997; Rao *et al.*, 1998). *Tithonia diversifolia* is a soft and succulent shrub belonging to the family Asteraceae (Compositae), and is commonly referred to as wild sunflower. Tithonia at 5 t ha^{-1} rate (on fresh weight basis) increased maize grain yield about one and half times higher than without inputs (Gachengo, 1996).

The capacity of any agroforestry system to enhance nutrient cycling depends both on soil fauna, environmental conditions (e.g. temperature, moisture, and aeration) and on management factors. Management aspects include the selection of tree species with appropriate phenology, rooting patterns and litter quality. Scientists need to understand the complex interactions among the above in order to realize the potential benefits of introducing agroforestry in a given environment (ICRAF, 1993).

In this study we seek to:

1) compare the effect of adding organic residues from agroforestry trees and shrubs on soil mineral N to that of inorganic source of N (fertilizer).
2) assess how these inputs of organic and inorganic sources of nutrients influence crop yields.

Materials and Methods

Study site description

The study was conducted on farm near Maseno (0°6' N, 34°35' E, and 1560 m above sea level), in Vihiga District of western Kenya. The area receives an average annual rainfall of 1800 mm in two rainy seasons; 'long rains' (March to July) and 'short rains' (September to January). However, during 1997, a total rainfall of 2037 mm was recorded with 1200 mm in the short rains, received because of the El nino phenomenon. Mean monthly temperature ranges between 14.6°C and 30.7°C. The soil at the experimental site was classified as Kandiudalfic Eutrodox (USDA, 1992). At the start of the study, the field had the following soil physical and chemical characteristics at 0-15 cm and 15-30 cm depths respectively: pH (1:2.5 soil water) 5.5, 5.5; organic carbon (g kg^{-1}soil) 15.5, 14.5; extractable soil inorganic P (mg kg^{-1}) 1.3, 0.9; exchangeable calcium (cmolc kg^{-1}) 4.03, 3.85; exchangeable potassium (cmolc kg^{-1}) 0.15, 0.13; clay (%) 41, 42; sand 33%, 33%; silt % 26%, 25%; porosity ranged between 50% and 60%. The soil is considered to be moderately P fixing with a soil P concentration corresponding to 310 mg P kg^{-1} adsorbed by the soil (Nziguheba *et al.*, 1998).

Experimental set-up and management

The present study was superimposed on an on-going larger experiment that was initiated in 1995, during the short rain season to evaluate six organic tree and shrub residues (*Tithonia diversifolia, Lantana camara, Calliandra calothyrsus, Senna spectabilis, Sesbania sesban* and *Croton megalocarpus*), as sources of nutrients in comparison with inorganic nutrients at six different N and P levels. The treatments were replicated four times in a randomized complete block design in plots of 7.5 m wide and 7 m long. The present study was conducted during the 1997 short rains with the following treatments using maize (*Zea mays* L.) hybrid as the test crop:

1) control: with no external inputs (Farmers' practice),
2) fertilizer input at: 120 kg N, 150 kg P and 100 kg K ha^{-1},
3) fresh biomass of *Tithonia diversifolia* at 5 tonnes (dry weight) ha^{-1} and
4) fresh biomass of *Senna spectabilis* at 5 tonnes (dry weight) ha^{-1}.

The trial initially did not include a "no input" control (no N and P), so a farmers' no fertilizer control was randomly assigned to one of the unutilized blank plots in each replicate. The site was relatively flat and there was no particular problem of runoff from plot to plot.

The amount of N and P added by the organic residues, depends on the chemical composition. Chemical composition was determined every season at the time of application. All the selected material contained fairly high N and P, but differed with respect to tannin, lignin, polyphenol levels (Table 4.1). In the fertilized plots, 120 kg N ha^{-1} rate was chosen as it is close to the total N applied for the different materials ranging between 136 kg N ha^{-1} to 183 kg N ha^{-1}. The rate is also sufficient to overcome N limitation to maize growth in these soils. The choice of the two residues (tithonia and senna) was based on the nutrient (N and P) concentration, plant residue quality index (PRQI)(Tian *et al*., 1995) and availability in the region for potential use by farmers.

Table 4.1: Chemical composition and plant residue quality index (PRQI) of tithonia and senna foliage

Plant residue	%N	%P	%Lignin	% Poly-phenols	C/N ratio	PRQI(%)
Senna spectabilis	3.3	0.21	9.0	1.03	10.89	10.26
Tithonia diversifolia	3.5	0.28	9.0	3.20	10.10	10.59

The difference between the two test materials as measured by PRQI, has turned out to be much smaller than initially thought (Table 4.1). However, the experience of many researchers indicate that tithonia decomposes faster than senna and represents high quality residues (Jama and Palm, Personal communications). In western Kenya, particularly around Maseno area, farmers grow tithonia as a part of live fences around their farms to mark boundaries or as hedges on contour. *Senna spectabilis* trees are also common. The two residues were therefore readily available.

Soil sampling

Soil samples were taken using 2-inch wide auger, from five different locations at two depth intervals (0-15 cm and 15-30 cm), within each plot. One composite sample was prepared for each 0-15 cm and 15-30 cm depths and they were analyzed for nitrate-N and ammonium-N contents of the soil using standard methods/procedures (Anderson and Ingram, 1993; Weaver *et al,* 1994). Inorganic N content was measured at the start of season and subsequently at 1, 2, 4, 8 and 12 weeks after treatments were applied.

Maize yield measurements

Maize grain and stover yields were estimated by harvesting the four central rows (3.0 m wide and 5.5 m long) leaving three guard rows on either sides and one metre each on either end. Within each row, two maize plants were left on either end as guard. The maize cobs were harvested, weighed and sub-samples obtained. The sub-samples (about 0.5 kg from each plot) were oven-dried and the cobs threshed. The threshing percentage was used to estimate the maize grain yield in tonnes per hectare. The maize stover from the net plot was harvested, weighed and sub-samples obtained. The sub-samples of stover were chopped into smaller pieces and were then oven-dried at 70°C. The ratio of dry weight to fresh weight and plot fresh weights were used to estimate the maize stover yield in tonnes per hectare.

Data analyses

The data collected were subjected to analyses of variance (ANOVA), to compare treatment effects on soil mineral N and maize yields. ANOVA was conducted using the GENSTAT 5 Committee (1993) statistical package. While sampling was conducted at different periods, the data were analyzed in a split-plot design with the applied treatments as the main plot factor and sampling period as the sub-plot factor. Treatment differences were evaluated using the least significance difference (LSD) at $P<0.05$. Standard error of difference of means (SED) was given.

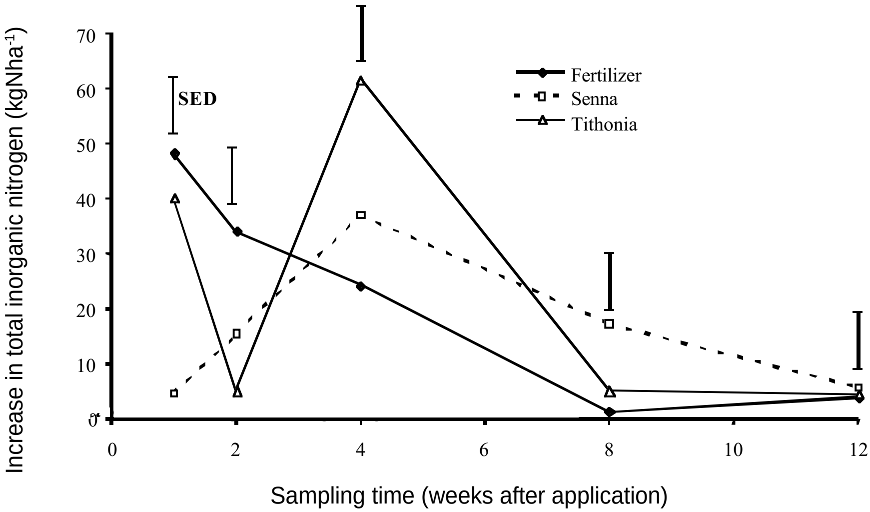
Results

Effect of fertilizer and organic residues on mineral nitrogen (N) in the soil

Total inorganic (mineral) nitrogen in the soil at the beginning of the season was at a similar level in all treatments. It increased rapidly after applying the materials and the onset of rains probably because of rapid nitrogen mineralisation in all treatments. At one week stage after addition of inputs, the highest amount of soil mineral N was observed in the urea fertilized plot (48 kg N ha^{-1}), followed by tithonia treated plots (40 kg N ha^{-1}), but lowest under senna (4.5 kg N ha^{-1}) (Figure 4.1).

After four weeks inorganic nitrogen decreased progressively until end of the experiment in all the treatments. However, for urea-fertilized plots, progressive decrease in mineral N was noted after one week. The highest contribution of mineral N to the soil by the organic residues was noted after four weeks and this was significantly higher with tithonia than senna. This could be due to rapid N mineralization by these residues. However, it is interesting to note that while soil N under tithonia was statistically higher than in senna at four weeks, it was higher under senna at 8 weeks after application (Figure 4.1).

Figure 4.1: Increase in mineral nitrogen (total mineral nitrogen in the top 0-30 cm soil depth) above the control (no input) over 12 weeks under different inputs of organic and inorganic nutrient sources



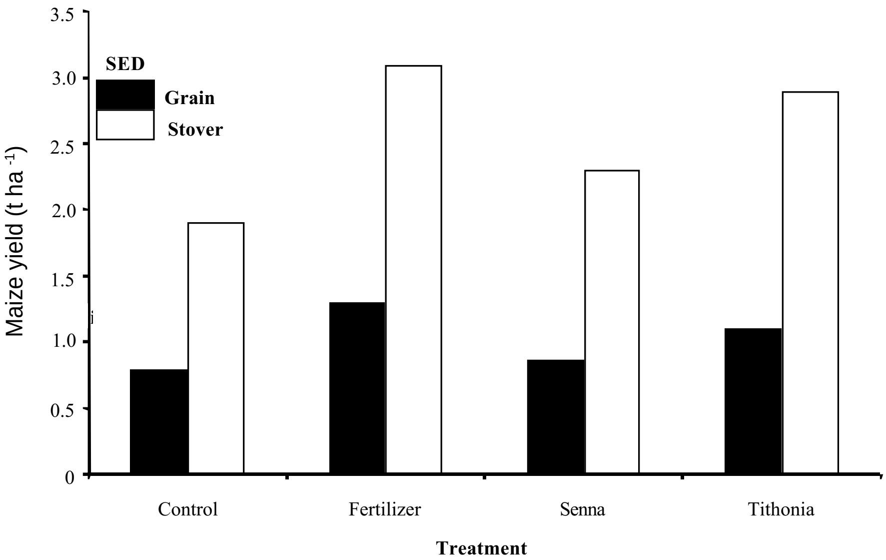
SED- Standard error of difference of means.

Effect of organic and inorganic sources of nutrients on maize yields

The treatments affected maize grain and stover yields in a similar way (Figure 4.2).

Maize without inputs (i.e. control) produced the lowest yields of 0.8 t grain and 1.9 t stover ha^{-1}. Application of senna residue did not increase the yields significantly. However, addition of fertilizer and tithonia biomass increased maize yields significantly over the control (Figure 4.2). Whereas the fertilized maize produced 1.3 t ha^{-1} grain and 3.1 t ha^{-1} stover, which represented about 63% increase over the respective yields in the control, maize yield following application of tithonia biomass yielded 1.1 t ha^{-1} grain and 3.0 t ha^{-1} stover per ha, which represented 38% and 58% respectively over the control. The fertilizer and tithonia treatments did not differ significantly between them. Senna treatment increased grain yield by only 6% over the no input control.

Figure 4.2: Maize yields affected by organic residues and fertilizer compared with no inputs during 1997 short rains in western Kenya



SED- Standard error of difference of means.

Discussion

Effect of organic and inorganic fertilizer inputs on soil mineral nitrogen

Tithonia decomposed and mineralized nutrients faster than senna probably because of its higher N and P concentration and lower C:N ratio (Table 4.1). The overall level of secondary compounds (lignin and polyphenols) in tithonia and senna were low compared with foliage of many trees and shrubs (Chesson, 1997; Palm and Rowland, 1997). It has been shown that tithonia residue has high microbial biomass hence higher microbial activities resulting in higher decomposition rate (Nziguheba and Palm personal communication). The high soluble carbon in the tissue of tithonia provides the necessary substrate for higher microbial activity. Tithonia contains 80% water that further contributes to rapid decomposition. Senna has comparatively high C:N ratio and therefore soil fauna has greater role to play in its decomposition (TSBF, 1996). Thus, decomposition of senna proceeded at a slow rate because of its overall low quality relative to that of tithonia. Senna released more N than tithonia towards the end of the season, i.e. it asynchronized to plant uptake. It has been shown that the presence of a low quality material with low N and P contents at the onset of rains extends the time period of nutrient availability to the plants (Myers *et al.*, 1994). Asynchrony has undesirable effects on the crops because nutrients are released when their demand by crops is low. The benefits of such residues to the crop may be through the long-term build-up of N rather than the direct use of N from the decomposing residues (Palm, 1995). Application of senna and tithonia did not significantly affect the soil mineral N among the treatments (Figure 4.1). Lack of treatment related differences in the soil could be due to:

1) plant uptake of the nutrients during the growing season, and
2) loss of nutrients from the soil by leaching and also by surface run-off after the release of the nutrients following mineralization.

Nitrogen mineralization for tithonia was high at the beginning of the trial and this decreased toward the end of the season. It is possible that this being a high quality residue, the fauna promoted early release of N and leaching took place at the onset of rains.

Effect of organic and inorganic fertilizer inputs on maize yield

The yield differences among treatments could be related to N and P availability to crops and release patterns by the organic residues. Higher yields obtained in the fertilizer treatments could be attributed to the nutrients being readily available from the fertilizers. Nutrients from organic residues must first undergo decomposition before they are available for crop uptake. In the organic residue treatments, nutrient availability depended on nutrient concentration and release in synchrony with crop needs. Tithonia had a higher N and P concentration and underwent rapid mineralization, while senna, which has low concentration of N and P, exhibited slow mineralization and/or immobilization during early stages of maize. Maize yields with tithonia were therefore significantly higher than with senna. Higher yields with use of organic residue have been reported. For instance, experiments conducted in western Kenya have demonstrated that higher yields can be obtained when organic residues have been incorporated (Gachengo *et al.*, 1999; Palm, 1996). Gachengo (1996) showed that tithonia can increase maize yields by one and half times higher than without tithonia input. Furthermore, tithonia was found to reduce P sorption capacity of the soil and increase crop yields particularly in P limited soils by making P available to crops (Nziguheba *et al.*, 1998; Palm, 1996). As the experimental site was deficient in P, the increased yield in tithonia green-manure treatment was probably related to the combined effect of rapid N and P mineralization and their increased availability to crops. Phosphorus availability might have also increased through reduction of P sorption by tithonia (Nziguheba *et al.*, 1998).

Conclusions

This is a one-season study conducted during the 1997 short rains (October 1997 to February 1998). The experimental period was characterized by above normal rainfall due to *El nino* effect. A rainfall of 1200 mm was received during this season and therefore maize did not grow well. Crop yields were low and variable. The results of the study and recommendations made should be considered in the above background of *El nino* effect, poor crop growth and high variability of observations.

Based on the results of this study, foliage of tithonia is a better organic residue for soil nutrient management than that of senna. Resource-poor farmers who cannot afford fertilizers may be encouraged to plant tithonia in hedges or in contours and use this organic residue to improve the soil nutrient status.

Organic residues such as senna, which release nutrients slowly, can be considered for long-term build up of soil fertility. It should preferably be incorporated into the soil much before crop sowing to synchronize nutrient release with the crop needs.

Because only two organic residues, tithonia and senna, were studied, there is still need to investigate and test more organic residues to identify potential alternatives to tithonia for different agroclimatic condition.

Acknowledgements

The Principal investigator was supported by ICRAF-ANAFE Postgraduate fellowship. The authors wish to thank Ms Eva Gacheru for managing the main field experiment and Mr. Dominic Tumbo and Mr. Romanus Ouma for assistance in the coordination of field activities.

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