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# Nitrogen Fertilizer Equivalency Values for Different Organic Materials Based on Maize Performance at Kabete, Kenya

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## Abstract

Decline in crop yields has been a major problem facing small holder farming in Kenya and the entire sub-Saharan region. This is attributed mainly to the mining of macronutrients due to cropping without external addition of adequate nutrients. Inorganic fertilizers are expensive hence unaffordable by most small holder farmers. Although organic nutrient sources are available, information about the right proportions of application is scanty.

An experiment was set up in 1999 at the National

Agricultural Research Laboratories (NARL) at Kabete, with the overall objective of determining nitrogen fertilizer equivalencies based on high quality organic inputs. The specific objectives of the study included determination of the nitrogen fertilizer equivalency values of *Tithonia diversifolia*, *Senna spectabilis* and *Calliandra calothyrsus* and the investigation of nitrogen use efficiency from combined organic and inorganic inputs.

The experiment consisted of maize plots to which freshly collected leaves of *Tithonia diversifolia* (tithonia), *Senna spectabilis* (senna) and *Calliandra calothyrsus* (calliandra) (all with % N >3) obtained from hedgerows grown *ex situ* (biomass transfer from outside) and urea (inorganic nitrogen source) were applied. Results obtained indicated that a combination of both organic and inorganic nutrient sources gave higher maize grain yield than when each is applied separately, except for tithonia whose sole application gave better grain yield than a combination of the same with mineral fertilizer. Maize grain yield production after organic and inorganic application was in the order of tithonia > tithonia+urea = calliandra+urea > urea > senna+urea > calliandra > senna > control. The percentage N recovery was highest in sole application of urea followed by a combination of both urea and tithonia while sole application of tithonia biomass had relatively lower percentage N recoveries. In both seasons, the mineral N content was high in sole application of tithonia than in senna and calliandra treatments. The three organic materials (senna, calliandra and tithonia) gave fertilizer equivalency values of 68%, 72% and 119% respectively.

**Key words:** N fertilizer equivalency, mineral-N, N-recovery

## Introduction

Decline in soil fertility is an acute problem facing small holder farming in Kenya. Due to the high cost and uncertain availability of inorganic fertilizers, it is important to provide alternative sources of nutrients such as organic materials. In the recent past there has been increased interest in the use of leaf biomass from woody perennials as a source of nutrients to annual crops (Kang *et al.*, 1990; Palm *et al.*, 1997; Mugendi *et al.*, 1999). The big challenge to this approach is ensuring that crops efficiently utilize nutrients from the applied organic materials. Synchronizing release of nutrients from decomposing biomass with crop

demand could lead to increased nutrient-use efficiency (Becker *et al.*, 1994; Mwale *et al.*, 2000b), and this in turn could minimize nutrient loss (Swift, 1987; Myers *et al.*, 1994; Mugendi *et al.*, 1999). The use of organic materials of differing quality in combination with inorganic fertilizers to optimize nutrient availability to annual crops is still a challenge to scientists currently.

Much research has been done to determine the use of organic plant materials as a source of nutrients in place of inorganic fertilizers and most of this research has revealed both advantages and disadvantages of combining nutrient sources (Palm *et al.*, 1997). However, little predictive understanding for the management of organic inputs especially in tropical agroecosystems is available (Palm *et al.*, 2001). It has been therefore difficult to give valid advice to farmers on the best organic N source for direct application and the right combinations with inorganic N source.

Although organic N sources have the potential to supply large quantities of N required by growing crops, to obtain maximum production and for more sustainability, they should be supplemented with inorganic fertilizers (Mugendi, 1997; Jama *et al.*, 2000; Vanlauwe *et al.*, 2001). The combination of inorganic N fertilizer with organic N sources is said to increase the rate of decomposition and mineralization (Mugendi *et al.*, 1999) of low quality materials. This coupled with the right time of application can improve synchrony of the N released from the decomposing biomass and nutrient requirement by annual crop, thereby, reducing N losses. This postulation is however, yet to be ascertained.

This research was therefore aimed at shedding light on the combined use of organic (tithonia, senna and calliandra) and inorganic N sources for farmers in the central region of Kenya. In addition, the study will provide information to link the fertilizer equivalency of organic materials (specific amount of an organic material that can have same effect on crop yield as a certain amount of inorganic fertilizer) with the resource quality as well as investigating the influence of N source on N uptake by maize.

## Materials and Methods

### Site description

The experiment was carried out at the National Agricultural Research Laboratories (NARL), Kabete, Kenya. The station is located at 36°46'E and 01°15'S and an altitude of 1650 m above sea level. The soils are mainly Humic Nitisols (FAO, 1990) that are deep and well weathered, and with the following chemical characteristics: pH =5.4; total N = 1.35g kg<sup>-1</sup>; extractable P = 27mg kg<sup>-1</sup>; carbon = 1.6%; exchangeable Ca, Mg, and K (cmol kg<sup>-1</sup>) of

5.8, 1.7, and 0.7 respectively; clay = 40%; sand = 23%; and silt = 37%. The mean annual rainfall is about 950 mm received in two distinct rainy seasons; the long rains (LR) received mid March to June and the short rains (SR) received mid October to December. The rainfall amount during the study period is shown in figure 15.5. The average monthly maximum and minimum temperature is 23.8°C and 12.6°C respectively.

## Experimental design and treatments

The experiment was designed and established by Tropical Soil Biology and Fertility (TSBF) Programme in 1999 with the aim of determining fertilizer equivalency values based on high quality organic materials. The experiment was a completely randomised block design (CRBD) with 10 treatments replicated 4 times. The plot size was 5.25 m by 5 m with an interplot spacing of 0.75 m. Urea and freshly collected leaves of tithonia, senna and calliandra (Table 15.1) were applied directly into the plots after which maize was planted. Collection of the organic materials was done by hand at the same location for both seasons. The leaves included the petioles, and in the case of senna and calliandra, they also included the rachis since these two have compound leaves. The calculation of the application amount of organic materials (that would give 60 kg N ha<sup>-1</sup>) (Table 15.2) was done on dry matter basis giving 1.3, 1.8 and 1.9 t ha<sup>-1</sup> for tithonia, senna and calliandra respectively. The percentages (%) indicated in Table 15.2 refer to the specific amount of N that was applied as different treatments in kg ha<sup>-1</sup>.

**Table 15.1:** Chemical properties of plant materials used at NARL, Kabete, Kenya

Season 1 (1999 short rains)							
Sample	%N	%P	%K	%Ca	%Mg	%PP	%Lignin
Tithonia	4.7	0.5	5.1	3.0	0.2	2.5	5.2
Senna	3.7	0.2	2.0	0.9	0.2	3.4	10.7
Calliandra	3.2	0.1	1.0	1.1	0.3	9.9	14.4
sed	0.2	0.03	0.3	0.3	0.1	1.0	1.8
Season 2 (2000 long rains)							
Tithonia	4.0	0.4	5.5	2.2	0.4	1.9	9.3
Senna	3.1	0.1	1.8	0.9	0.2	1.8	10.9
Calliandra	2.4	0.1	0.7	1.1	0.3	12.4	17.5
sed	0.2	0.03	0.3	0.3	0.1	1.0	1.8

Abbreviations: PP= Polyphenols  
sed = Standard error of differences

**Table 15.2:** Experimental Treatments at NARL Kabete, Kenya.

Trt.	Inorganic N (kg ha <sup>-1</sup> )	Organic N (kg ha <sup>-1</sup> )
1. * (Control)	0	0
2.	30	30 (50% tithonia)
3.	0	60 (100% tithonia)
4. *	60	0
5.	30	30 (50% senna)
6.	0	60 (100% senna)
7.	30	30 (50% calliandra)
8.	0	60 (100% calliandra)
9. *	35	0
10. *	100	0

\* These are the treatments that were used in plotting of the response curve, which was used in the calculation of the nitrogen fertilizer equivalency values of the three organic inputs.

Selection of tithonia, senna and calliandra as the organic N sources was based on their contrasting qualities with respect to polyphenols and rates of decomposition (Gachengo *et al.*, 1999; Mutuo *et al.*, 1999). The chemical characteristics of these three organic inputs used for the two cropping seasons are shown in Table 15.1.

### Sampling and analyses

Plant samples were oven-dried at 35°C for 48 hours then ground to pass through a 1.0 mm sieve and analyzed for total N, P, K, Ca, and Mg by Kjeldahl digestion with concentrated sulfuric acid (Anderson and Ingram, 1993; ICRAF, 1995). Nitrogen and phosphorus were determined colorimetrically (Parkinson and Allen, 1975) while potassium was by flame photometry (Anderson and Ingram, 1993). Magnesium and calcium was by atomic absorption spectrophotometer at wavelength of 2852 and 4227 respectively. Determination of lignin was done using the acid detergent fiber (ADF) method as described by Van Soest (1963). Total soluble polyphenols were analyzed by extraction using 50% aqueous methanol (Anderson and Ingram, 1993). The plant material to extractant ratio was 0.1 g / 50 ml and phenols were analyzed colorimetrically using the Folin-Ciocalteu reagent as described by Constantinides and Fownes (1994).

## Data Analysis

### Fertilizer equivalency value

Fertilizer equivalencies (FE) of organic materials were obtained by comparing the yield from the organic material treatments to that of the nitrogen (N) response curve from inorganic N fertilizer (Mutuo *et al.*, 1999). Calculation for the corresponding N fertilizer equivalent for an organic material was obtained from the quadratic equation ( $Y = aFE^2 + bFE + c$ ) exhibited by the N response curves. The following formula for solving quadratic equations was used:

$$FE = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Where a, b, and c are constants, with values -0.0001, 0.0252, and 1.8297 respectively for 1999 short rains (Figure 15.1) and -0.0001, 0.0284, and 2.0827 respectively for 2000 long rains (Figure 15.2).

**Figure 15.1:** Season 1 biomass yield response to levels of N at NARL – Kabete, Kenya, 1999

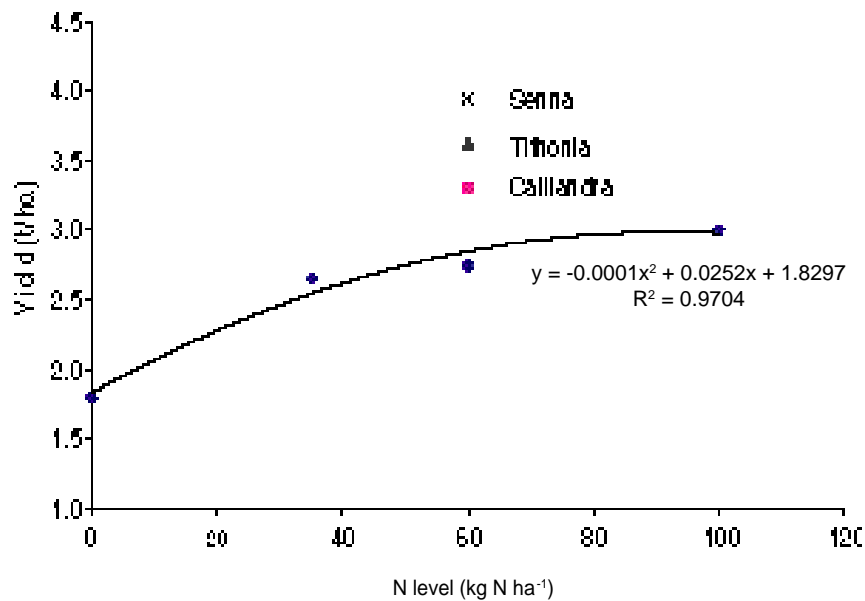
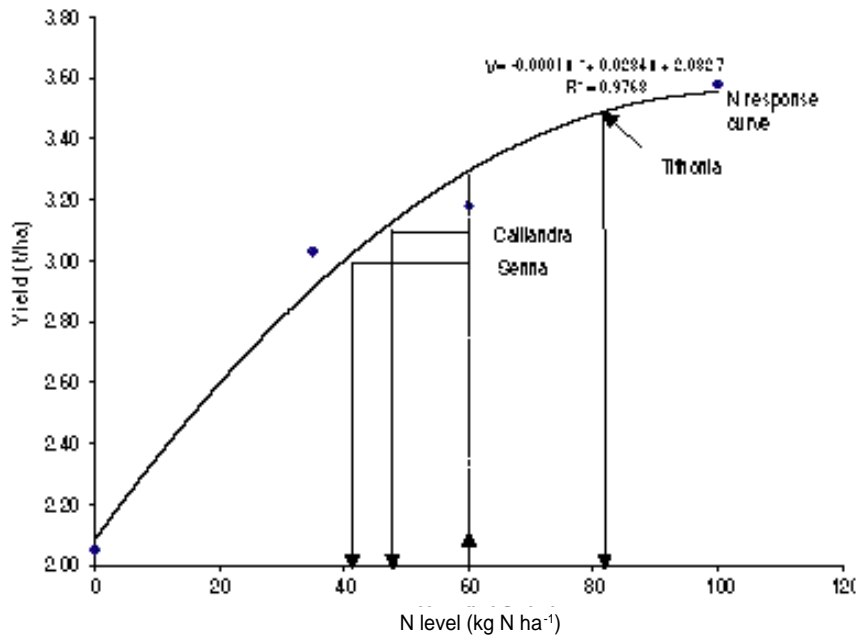


Figure 15.2: Season 2 grain yield response to N levels at NARL – Kabete, Kenya, 2000



In order to compare the fertilizer equivalencies of organic materials, the fertilizer equivalency (FE) % values were calculated as follows:

$$\%FE = \frac{FE}{N \text{ applied}} \times 100$$

Where: N applied = actual amount of N applied (100% organic/inorganic).

Source: Mutuo *et al.* (1999).

### Maize yields

To compare treatment effects on maize grain yield, yields were converted to relative increase compared to the control:

$$\text{Yield increase (\%)} = \frac{\text{Yield}_{\text{treatment}} - \text{Yield}_{\text{control}}}{\text{Yield}_{\text{control}}} \times 100$$

(Source: Gachengo *et al.*, 1999)

### Nitrogen uptake

Nitrogen uptake by the maize crop was determined by multiplying the grain, stover and core yields with the nitrogen concentration in the specific components. Nitrogen recovery was determined as shown below:

$$\text{Nitrogen recovery (\%)} = \frac{(\text{N uptake}_{\text{treatment}} - \text{N uptake}_{\text{control}})}{\text{Amount of nitrogen applied}} \times 100$$

### Statistical comparisons

Treatment effects on soil N availability and maize yield were analyzed using Genstat 5 for windows (Release 4.1) computer package. Treatment means found to be significantly different from each other were separated by Least Significant Differences (LSD) at  $P < 0.05$ .

## Results and Discussions

### Nitrogen fertilizer equivalencies of tithonia, calliandra and senna

The study sought to attain this by investigating the performance of maize crop supplied with green leaves from the organics as compared to maize grown with urea as N source. Due to poor rainfall distribution during the 1999 short rains, maize crop was harvested six weeks before maturity hence no grain yields were obtained. Biomass yield data was therefore used in calculating the fertilizer equivalencies for the organics. Results obtained showed that maize biomass yields were 3.3, 3.6 and 3.9 t ha<sup>-1</sup> for 60 kg N ha<sup>-1</sup> of calliandra, tithonia and senna treatments respectively. As shown in Figure 15.1, these yields were higher than the biomass yields from any of the inorganic N source treatments whose highest yield was only 3.0 t ha<sup>-1</sup>. Thus, the values for the yields obtained from the three organic materials fell high above the response curve. Hence, the fertilizer equivalencies for the organic materials could not be estimated from the N response curve. These differences in the yields obtained from the organic and inorganic N sources could be attributed to the poor rainfall distribution during that growing season and the timing of the N application. Much of the rainfall was received late November, 1999 and early December, 1999 and scarcely any rainfall in January, 2000 which was the tussling stage for the maize. Also, the fact that all the 60 kg N from the organics was applied when there was moisture (at planting) unlike for urea which was applied in split (20 kg N at planting and 40 kg N applied after five weeks) could also be a partial explanation for the better performance of the maize crop supplied with the organics. This is mainly because the application of the second split of the urea was followed by a dry spell. Hence, the growing maize crop might not have utilized this portion of the urea, thus leading to the low maize biomass yields from urea treatment. The relatively high biomass yield from organic treatments could also be due to other

positive effects of the organic materials on soil physical properties (like moisture retention) and chemical properties (other micronutrients like calcium and magnesium) (Chen and Avnimelech, 1986; Wallace, 1996; Mutuo *et al.*, 1999).

A better maize performance was observed during the 2000 long rains season. Maize grain yields from the organic treatments were 3.6, 3.1 and 3.0 t ha<sup>-1</sup> for 60 kg N ha<sup>-1</sup> tithonia, calliandra and senna respectively compared to the highest yields from urea treatments of about 3.6 t ha<sup>-1</sup> (Figure 15.2). This gave fertilizer equivalency values of 119%, 72% and 68% for tithonia, calliandra and senna. The implication was that tithonia biomass performed better than an equivalent amount of inorganic fertilizer in improving maize grain yield while calliandra and senna performed relatively lower to an equivalent amount of inorganic N source. The high fertilizer equivalency value for tithonia compared to the other two organic materials (senna and calliandra) could be attributed to its low polyphenol content compared to senna and calliandra. Hence, decomposition rate and subsequent N release is higher in tithonia green biomass (Gachengo *et al.*, 1999) as compared to senna and calliandra (Lehmann *et al.*, 1995). The N content in the material also influence decomposition and N release as Mutuo *et al.* (1999) noted in different sites in East and Southern Africa. The conclusion was that fertilizer equivalency value of organic materials is proportional to the N content. However, from the results we obtained, the fertilizer equivalency values for senna and calliandra (68% and 72% respectively) did not differ significantly despite the 3.1 and 2.4% N content in the two organic materials. This could be an indication of more conspicuous residual effect (from season one) in the calliandra treatment than in senna treatment.

Fertilizer equivalency values for tithonia and calliandra were almost twice the values reported by Mutuo *et al.* (1999) for the same organic materials in their trial in Western Kenya. This could be attributed to the difference in the climatic conditions. Western Kenya received adequate rains, while the Central region (Kabete trial site) was characterized by poor rainfall distribution during the two seasons when this research was carried out.

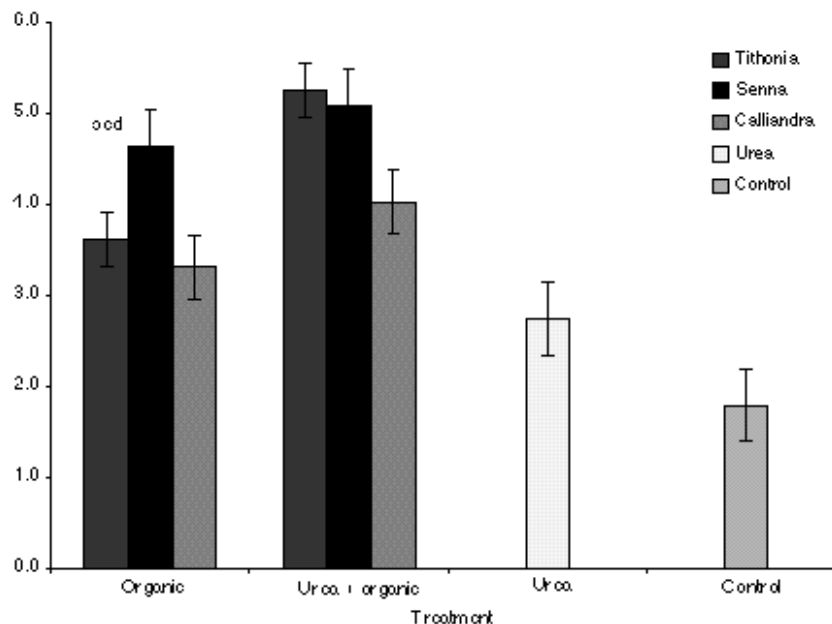
As per the study findings, tithonia green biomass can be recommended for direct application while senna green biomass can be applied in combination with inorganic fertilizer. Calliandra leaf biomass on the other hand may not be recommended for direct application due to the high polyphenol content (11.1%) as compared to the suggested critical level of 4.0% (Palm *et al.*, 1997; Palm *et al.*, 2001) and also because of its low nitrogen content (2.4% N). Therefore, as suggested in the organic matter management decision tree (Delve *et al.*, 2000; Palm *et al.*, 2001), calliandra leaf biomass may give better results when mixed with inorganic N fertilizer.

### Maize performance as influenced by the N source

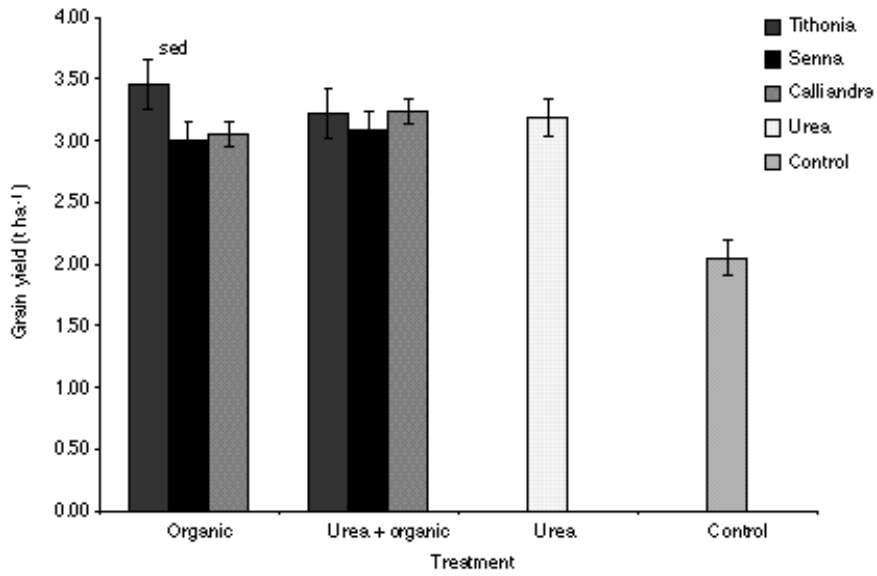
Maize yields were dependent on the N source (Figure 15.3 and Figure 15.4). During the 1999 short rains, biomass yield obtained from a combination of either of the three organic inputs with inorganic N source differed significantly from biomass yield obtained from sole application of inorganic N source (Figure 15.3). It was also found that maize biomass yield obtained from tithonia + urea treatment was significantly higher compared to maize biomass yield obtained from sole tithonia and sole urea treatments. Approximately twice as much maize biomass yield was obtained with combination of tithonia and urea as compared to urea applied alone. This could be an indication of better results in combining organic and inorganic N source, which could be attributed to better synchrony of nutrient availability to maize crop demand. Separate application of either tithonia or urea did not show significant differences.

Sole application of senna green biomass and a combination of the same with urea had significantly higher maize biomass yield than urea applied separately. Calliandra, calliandra + urea and sole urea treatments did not show any significant differences from each other. It was also found out that the control gave significantly lower maize biomass yield compared to all the other treatments.

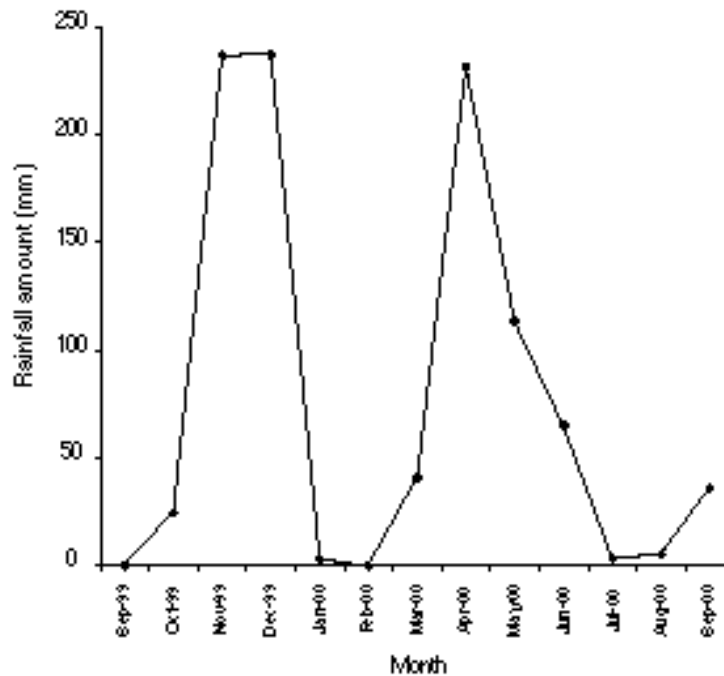
**Figure 15.3:** The effect of combining organic-inorganic N sources on maize biomass yield during 1999 short rains at NARL – Kabete, Kenya



**Figure 15.4:** The effect of combining organic-inorganic N sources on maize grain yield during 2000 long rains at NARL – Kabete, Kenya



**Figure 15.5:** Rainfall data (1999-2000) at Kabete, Kenya



Similar results were reported by Jama *et al.* (2000) who observed higher maize yields obtained from a combination of tithonia and phosphorus fertilizer in their work in western Kenya. Other researchers have observed greater maize production through application of high-quality organic inputs like tithonia in combination with inorganic fertilizer as compared to sole application of mineral fertilizers (Gachengo, 1996; Palm *et al.*, 1997).

Results obtained during the 2000 long rains season revealed that all other treatments had significant increase on maize grain yield above the control (Figure 15.4). Tithonia green manure increased maize grain yield by about 71.4% while calliandra and senna increased grain yield by 48% and 43% respectively. A percentage grain yield increase of about 52% above control was realized from sole urea treatment. Maize grain yields from combined use of organic-inorganic N sources were dependent on the organic material used. Although there was significantly higher maize grain yield from tithonia green biomass as compared to senna and calliandra, grain yield obtained from sole application of any of the organic materials and a combination with mineral fertilizer did not significantly differ from each other.

The relatively better results realized from tithonia sole application than a combination with mineral N source and sole application of urea (though not significantly different) could still be attributed to other indirect effects to the soil such as moisture retention (Wallace, 1996; Lehmann *et al.*, 1999) and addition of other macro- and micronutrients. Nziguheba (2001), also reported increase in maize growth with application of tithonia green biomass which (in addition to increased N availability), was attributed to increased labile P as compared to inorganic inputs.

As noted also during 1999 short rains, time of application might have as well played a major role in maize performance. All the tithonia green biomass was applied at once at planting when there was rain while only one third of the urea was applied at planting. Two thirds of the urea was applied five weeks later, which was followed by a dry spell, hence, insufficient amounts of the urea N were available to the growing crop.

Lower maize grain yields obtained from sole application of either calliandra or senna, could be attributed to N immobilization or reduced N release as Mwale *et al.* (2000b) also noted in their study at Chalimbana, Zambia. Other researchers also observed that, large portion of N from a slowly decomposing biomass may be incorporated into soil organic matter fractions (Lehmann *et al.*, 1999) or immobilized into forms not readily available to annual crops (Mugendi *et al.*, 1999). Therefore tithonia green biomass can be recommended for direct incorporation for soil fertility improvement (Delve *et al.*, 2000; Palm *et al.*, 2001).

### Nitrogen uptake and total %N recovery by maize

The results revealed that, nitrogen concentration in the grain, stover and core yields differed significantly among N sources (Table 15.3). Nitrogen uptake ranged from 93.3 to 131.9 kg ha<sup>-1</sup>. From the study findings, it was noted that the inorganic fertilizer (urea) applied treatment gave the highest N uptake while control had the lowest. Tithonia + urea and urea treatments were significantly higher than the control. Above ground yield from urea sole application had about 131.9 kg ha<sup>-1</sup> total N uptake while tithonia + urea gave 114.3 kg ha<sup>-1</sup>. This relatively high N uptake from the two treatments could be attributed to the readily available N from the urea. The N uptake by maize that received tithonia green biomass alone as nitrogen source was about 97.6 kg ha<sup>-1</sup>, which was not significantly different from the control.

**Table 15.3:** Nitrogen recovery by maize crop in long rains 2000 at NARL, Kabete, Kenya

Treatment	N applied (kg N ha <sup>-1</sup> )	Nitrogen uptake (kg N ha <sup>-1</sup> )	%N		Total % N recovery
			Grain	Stover	
Control	0	93.3	1.7	0.63	N/A
Tithonia + Urea	60	114.3	1.9	0.9	35
Tithonia	60	97.6	1.8	0.8	7.2
Urea	60	131.9	2.0	1.1	64.3
sed	-	16.4	-	-	N/A

The apparent percentage N recovery by maize crop that received sole tithonia green biomass was found to be 7.2% while 35% was recovered in tithonia + urea treatment. Sole urea treatment had a 64.3% nitrogen recovery. However, these values might not have reflected the actual N recoveries by the maize. This is because the material used was not labelled hence it was not possible to follow up the applied nitrogen (either in organic or inorganic form). Therefore, calculated total % N recovery values obtained in the study were meant to be estimates to the actual recoveries.

Nitrogen recovery by the maize crop that received sole application of urea and the one that received a combination (inorganic-organic N source), was significantly higher compared to nitrogen recovered by maize that received sole tithonia green biomass. The high N recoveries by maize crop planted in sole urea and tithonia + urea applications were an indication that there was less N loss from soil-plant system. Therefore, the growing maize crop took up a large percentage of the N supplied by either the inorganic or inorganic-organic inputs. This justifies split application of urea.

Grain yield accounted for a greater portion of the recovered N than either stover yield or the core. This was also noted by Mugendi *et al.* (2000) in their work in the subhumid highlands of Kenya.

Other researchers working on different N sources (organic and inorganic inputs) also reported a percentage N recovery ranging from 25% to 111% (Westerman *et al.*, 1972; Kruijs *et al.*, 1988; Christianson *et al.*, 1990; Gachengo *et al.*, 1999). In this study, nitrogen recovery values from tithonia green biomass was found to be relatively lower than the values Gachengo *et al.* (1999) observed using the same organic material in a study in Western Kenya. This could be due to differences in environmental conditions especially rainfall distribution between the two sites. However, the N recovery value from inorganic fertilizer (urea) agrees with the findings of Chabrol *et al.* (1988) in a study in Bedfordshire, England as well as what Mugendi *et al.* (1999) found out in their studies in the subhumid highlands of Kenya.

## Conclusions

Tithonia had a fertilizer equivalency value of 119% while calliandra and senna had 72% and 68% respectively. The extent to which an organic material will perform comparable to mineral fertilizer, is dependent on several factors especially the quality of the organic materials, climatic factors and site characteristics. Although higher biomass and grain yields were obtained from tithonia sole application compared to sole urea application, maize crop supplied with sole urea was found to recover nitrogen at a higher rate than maize crop supplied with tithonia biomass. It is evident that the effect of external inputs on crop N use efficiency is dependent on the organic material used and climatic conditions (especially rainfall amount) prevailing throughout the growing period of the annual crop.

*Tithonia diversifolia* can be used as a source of nitrogen in place of mineral fertilizer and smallholder farmers should be encouraged to use tithonia green biomass for annual crops especially in areas of inadequate rainfall. *Senna spectabilis* and *Calliandra calothyrsus* green biomass should be recommended for use in combination with inorganic N source for better results. A similar research should be recommended for other organic materials and at different agroecological zones as well as to establish other specific beneficial effects of organic inputs on annual crop yields.

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## References

- Anderson, J.M. and Ingram, J.S.L. (1993) *Tropical Soil Biology and Fertility: A Handbook of Methods*. CAB International, Wallingford, U.K.
- Becker, M., Ladha, J.K. and Ottow, J.C.G. (1994) Nitrogen losses and lowland rice yield as affected by residue nitrogen release. *Soil Science Society of America Journal* 58: 1660-1665.
- Chabrol, M., Powlson, D.S. and Hornby, D. (1988) Uptake by maize (*Zea mays* L.) of nitrogen from <sup>15</sup>N-labelled dazomet, <sup>15</sup>N-labelled fertilizer and from the soil microbial biomass. *Soil Biology and Biochemistry* 20: 517-523.
- Chen, Y., Avnimelech, Y., (Eds) (1986) *The role of organic matter in modern Agriculture*. Martinus Nijhoff Publishers, Dordrecht. The Netherlands.
- Christianson, C.B., Bationo, A., Henao, J. and Vlek, P.L.G. (1990) Fate and efficiency of N fertilizers applied to millet in Niger. *Plant and Soil* 125: 221-231.
- Constantinides, M. and Fownes, J.H. (1994) Nitrogen mineralization from leaves and litter of tropical plants: relationship to nitrogen, lignin and polyphenol concentrations. *Soil Biology and Biochemistry* 26: 49-55.
- Delve, R., Gachengo, C., Adams, E., Palm, C., Cadisch, G. and Giller, K.E. (2000) The Organic Resource Database. In: *The Biology and fertility of Tropical soils: A TSBF Report 1997- 1998*. PP 20-22.
- FAO (Food and Agriculture Organization) (1990) *New Environmental Threat: Declining Soil Fertility*. Land and Water Technical Newsletter.
- Gachengo, C.N. (1996) Phosphorus release and availability on addition of organic materials to phosphorus fixing soils. M.Phil. thesis. Moi University, Eldoret, Kenya.
- Gachengo, C.N., Palm, C.A., Jama, B. and Otieno, C. (1999) Tithonia and senna green manures and inorganic fertilizers as phosphorus sources for maize in Western Kenya. *Agroforestry Systems* 44, 21-36.
- ICRAF (1995) *Laboratory Methods for Soil and Plant Analysis: Version 1.1*. Nairobi.
- Jama, B., Palm, C.A., Buresh, R.J., Niang, A., Gachengo, C., Nziguheba, G. and Amadalo, B. (2000) Tithonia diversifolia as a green manure for soil fertility improvement in western Kenya: A review. *Agroforestry systems* 49: 201-221.
- Kang, B.T., Reynolds, L. and Atta-Krah, A.N. (1990) Alley farming. *Advances in Agronomy* 43: 315-359.
- Kruijs, A. C. B. M. van., Wong, M. T. F., Juo, A.S.R. and Wild, A., (1988) Recovery of <sup>15</sup>N-labelled fertilizer in crops, drainage water and soil using monolith lysimeters in south-east Nigeria. *Journal of Soil Science* 39: 483-492.
- Lehmann, J., Schroth, G., Zech, W. (1995) Decomposition and nutrient release from leaves, twigs and roots of three alley-cropped tree legumes in Central Togo. *Agrofor Syst.* 29: 21-36.
- Lehmann, J., Feilner, T., Gebauer, G., Zech, W. (1999) Nitrogen uptake of sorghum (*Sorghum bicolor* L.) from tree mulch and mineral fertilizer under

- high leaching conditions estimated by nitrogen-15 enrichment. *Biology and Fertility of Soils* 30: 90-95.
- Mugendi, D.N. (1997) Tree Biomass decomposition, Nitrogen Dynamics and Maize growth Under Agroforestry conditions in the sub-humid highlands of Kenya. PhD Thesis, University of Florida, Gainesville, Florida, U.S.A.
- Mugendi, D.N., Nair, P.K.R., Mugwe, J.N., O'Neill, M.K., Swift, M.J. and Woome, P. (1999) Alley cropping of maize with Calliandra and Leucaena in the Sub-humid highlands of Kenya. Part 2: Biomass decomposition, N mineralization, and N uptake by Maize. *Agroforestry Syst.* 46: 51-64.
- Mugendi, D.N., Nair, P.K.R., Graetz, D.A., Mugwe, J.N. and O'Neill, M.K. (2000) Nitrogen recovery by alley-cropped maize and trees from 15N-labeled tree biomass in the subhumid highlands of Kenya. *Biol. Fertil. Soils* 31: 97-101.
- Mutuo, P. K., Marandu, A.E., Rabeson R. Mwale, M. Snapp, S. and Palm, C.A. (1999) Nitrogen fertilizer equivalencies based on organic input quality and optimum combinations of organic and inorganic N sources: Network trial results from East and Southern Africa. In SWNM Report on the combating Nutrient Depletion – East Africa Highlands consortium.
- Mwale, M., Mapiki, A. and Phiri, L.K. (2000a) Optimal combinations of organic and inorganic N sources. In: *The Biology and fertility of Tropical soils: A TSBF Report 1997- 1998.* PP 38-40.
- Mwale, M., Mapiki, A. and Phiri, L.K. (2000b) To synchronize nutrient availability with plant uptake. In: *The Biology and fertility of Tropical soils: A TSBF Report 1997- 1998.* PP 40-41.
- Myers, R.J.K., Palm, C.A., Cuevas, E., Gunatilleke, I.U.N. and Brossard, M. (1994) The synchronization of nutrient mineralization and Plant nutrient demand, In the Biological management of soil fertility, Woome, P.L. and Swift, M.J., (eds) John Wiley & Sons, Chichester.
- Nziguheba, G. (2001) Improving phosphorus availability and maize production through organic and inorganic amendments in phosphorus deficient soils in Western Kenya. PhD thesis, Katholieke University, Leuven.
- Palm, C. A. Myers, R. J. K. and Nandwa, S. M. (1997) Combined use of organic and inorganic nutrient Sources for soil fertility Maintenance and replenishment. In Buresh, R. J., and Sanchez, P.A., (eds). *Replenishing soil fertility in Africa* SSSA spec. Publ. 51. SSSA, Madison, WI.
- Palm, C.A., Gachengo, C.N., Dalve, R.J., Cadisch, G. and Giller, K.E. (2001) Organic inputs for soil fertility management in tropical agroecosystems: application of an organic resource database. *Agriculture, Ecosystems and Environment.* 83: 27-42.
- Parkinson, J.A. and Allen, S.E. (1975) A wet oxidation procedure suitable for the determination of nitrogen and mineral nutrients in biological materials. *Communications in Soil Science and Plant Analysis* 6: 1-11.
- Shepherd, G., Buresh, R.J. and Gregory, P.J. (2000) Land use affects the distribution of soil inorganic nitrogen in smallholder production systems in Kenya. *Biol. Fertil. Soils* 31: 348-355.
- Swift, M.J. (1987) Tropical Soil Biology and Fertility: Interregional research planning workshop, special issue 13, in biology international IUBS, Paris.



- Thonnissen, C., Midmore, D.J., Ladha, J.K., Olk, D.C. and Schmidhalter, U. (2000) Legume decomposition and nitrogen release when applied as green manures to tropical vegetable production systems. *Agron. J.* 92: 253-260.
- Vanlauwe, B., Aihou, K., Houngnandan, P., Diels, J., Sanginga, N. and Merckx, R. (2001) Nitrogen management in 'adequate' input maize-based agriculture in the derived savanna benchmark zone of Benin Republic. *Plant and Soil* 228: 61-71.
- Van Soest, P.J. (1963) Use of detergents in the analysis of fibrous feeds. II: A rapid method for the determination of fibre and lignin. *Journal of the Association of Agricultural Chemists* 46: 829-835.
- Wallace, J.S. (1996) The water balance of mixed tree-crop systems. In: Ong, C.K., and Huxley, P. (eds) *Tree-crop interactions, a physiological approach*. CAB International, Wallingford, UK, pp 73-158.
- Westerman, R.L., Kurtz, L.T. and Hauck, R.D. (1972) Division s-4 - soil fertility and plant nutrition: Recovery of <sup>15</sup>N-labeled fertilizers in field experiments. *Soil Science Society of America Proc.*, Vol. 36: 82-86.

