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Nitrogen fertilizer equivalencies of organics of differing quality and optimum combination with inorganic nitrogen source in Central Kenya

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Abstract

Decline in crop yields is a major problem facing smallholder farmers in Kenya and the entire Sub-Saharan region. This is attributed mainly to the mining of major nutrients due to continuous cropping without addition of adequate external nutrients. In most cases inorganic fertilizers are expensive, hence unaffordable to most smallholder farmers. Although organic nutrient sources are available, information about their potential use is scanty. A field experiment was set up in the sub-humid highlands of Kenya to establish the chemical fertilizer equivalency values of different organic materials based on their quality. 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) and urea (inorganic nitrogen source) were applied. Results obtained for the cumulative above ground biomass yield for three seasons indicated that a combination of both organic and inorganic nutrient source gave higher maize biomass yield than when each was applied separately. Above ground biomass yield production in maize (t ha^{-1}) from organic and inorganic fertilization was in the order of senna+urea (31.2), tithonia+urea (29.4), calliandra+urea (29.3), tithonia (28.6), senna (27.9), urea (27.4), calliandra (25.9), and control (22.5) for three cumulative seasons. On average, the three organic materials (calliandra, senna and tithonia) gave fertilizer equivalency values for the nitrogen contained in them of 50, 87 and 118%, respectively. It is therefore recommended that tithonia biomass be used in place of mineral fertilizer as a source of nitrogen. The high equivalency values can be attributed to the synergetic effects of nutrient supply, and improved moisture and soil physical conditions of the mulch. However, for sustainable agricultural production, combination with mineral fertilizer would be the best option.

Introduction

Small scale farming in Kenya and the entire sub-Saharan region has been adversely affected by soil fertility decline. This could be reversed with external nutrient inputs. Due to the high cost and uncertain availability of inorganic fertilizers (Mwaura and Woomer 1999), it is important to find alternative sources of nutrients such as organic materials. In the recent past there has been increased interest in the use of leafy biomass from woody perennials as a source of nutrients to annual crops (Kang et al. 1990; Palm et al. 1997; Mugendi et al. 1999). However, different organic resources have differing chemical compositions that determine residue decomposition rates, consequently affecting nutrient release patterns. According to Palm et al. (2001), nitrogen, polyphenol and lignin contents are the major residue quality factors determining the decomposition rate of organic materials and the subsequent nutrient release. As suggested in the organic resource database (Palm et al. 2001), these factors have also been indicated to influence the management options of organic materials.

Much research has been done to determine the use of organic plant materials as a source of nutrients in place of or in combination with inorganic fertilizers, and most of this research has revealed both advantages and disadvantages of combining nutrient sources (Palm et al. 1997). However, information on nutrient content (which is variable between sites) and quality of organic inputs used is often lacking (Murwira et al. 2002) and thus, little predictive understanding for the management of organic inputs, especially in tropical agroecosystems, is available (Palm et al. 2001). It has therefore been difficult to give valid advice to farmers on the best organic N source for direct application and the right combinations of the organic with inorganic N sources.

Although organic residues have the potential to supply large quantities of N required by growing crops, large amounts of material are needed and the method is labour intensive, hence not widely adopted by farmers in sub-Saharan Africa. Therefore, under low-input conditions it has been recommended to use as much organic nutrient as possible and supplement with inorganic nutrient sources (Mugendi 1997; Palm et al. 1997; Jama et al. 2000; Vanlauwe et al. 2001). This trend may be reversed as more fertilizers become available. Combination of inorganic N fertilizer with organic N sources is said to increase the rate of decomposition and mineralization (Mugendi et al. 1999) of organic 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 crops, thereby reducing N losses (Swift 1987; Myers et al. 1994; Mugendi et al. 1999) and increasing crop yields (Becker et al. 1994; Mwale et al. 2000a,b).

The objectives of this study were (1) to provide information to link the fertilizer equivalency (specific amount of an organic material that can have the same effect on crop yield compared to a certain amount of inorganic fertilizer) of organic materials with the resource quality, and (2) to establish the interactive effect on the combined use of organic and inorganic N sources on maize yields. Previous research in the study region and similar agroecosystems has shown that fertilizer equivalency values of organic resources are directly related to nitrogen content in the organic material (Murwira et al. 2002). It has also been hypothesised that a combination of inorganic fertilizer with organic inputs could give higher economic gain to a resource-poor farmer than either applied separately (Gachengo et al. 1999).

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 at an altitude of 1650 m above sea level. The soils are mainly Humic Nitisols (FAO-UNESCO 1990) that are deep and well weathered. The soil pH is 5.4, total N 1.35 g kg^{-1}, extractable P 27 mg kg^{-1}, carbon 16 g kg^{-1}, exchangeable Ca, Mg, and K (cmol kg^{-1}) 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 from mid-March to June and the short rains (SR) received from mid-October to December. The average monthly maximum and minimum temperatures are 23.8 and 12.6 °C, respectively.

Plant material selection

Tithonia diversifolia, *Senna spectabilis* and *Calliandra calothyrsus* were used in this experiment as organic N sources. The selection was based on their contrasting qualities with respect to nitrogen, lignin and polyphenol contents and rate of decomposition. Calliandra had the highest polyphenol content (11.1%), followed by senna (2.6%), while tithonia had the lowest polyphenol content (2.2%). The average nutrient concentrations of these organics were 4.4% N, 0.5% P, 5.3% K for tithonia, 3.4% N, 0.2% P, 1.9% K for senna and 2.8% N, 0.1% P, 0.9% K for calliandra.

Experimental design

The experiment was a completely randomised block design (CRBD) with 10 treatments replicated four times. Table 1 shows the experimental treatments. Four treatments (control, 35 kg ha^{-1} urea-N, 60 kg ha^{-1} urea-N, and 100 kg ha^{-1} urea-N) were to be

Table 1. Experimental treatments for the nitrogen (N) trial at NARL Kabete, Kenya.

Treatment	Inorganic N (kg ha^{-1})	Organic N (kg ha^{-1})
1[a] (Control)	0	0
2	30	30 (50% TD)
3	0	60 (100% TD)
4[a]	60	0
5	30	30 (50% SS)
6	0	60 (100% SS)
7	30	30 (50% CC)
8	0	60 (100% CC)
9[a]	35	0
10[a]	100	0

TD – *Tithonia diversifolia*; SS – *Senna spectabilis*; CC – *Calliandra calothyrsus*.
[a]These are the treatments that were used in plotting the response curve, which was used in the calculation of the nitrogen fertilizer equivalency values of the three organic inputs. The percentages (%) refer to the specific amount of nitrogen (N) that was applied as organic or inorganic source. In this experiment, the rate of N applied for the combined nutrient sources was 60 kg N ha^{-1}(100%) and this was added every season for the first two seasons.

used to draw the N response curve. Tithonia, senna and calliandra treatments were used to establish the fertilizer equivalencies of the three organic materials, while the treatments which contained a combination of the organics with urea were used to investigate the additive effect of the combination (organic + inorganic) on maize grain yields.

The study was conducted for three seasons (1999 short rains, 2000 long rains and 2000 short rains) whereby the treatments were repeated for the second season and the residual effect was studied during the third season. The plots measured 5.25 m by 5 m with an interplot spacing of 0.75 m.

Trial management

Collection of the leaves of the organic materials was done by hand at the same location. Urea and freshly collected leaves of tithonia, senna and calliandra were surface applied directly, after which the maize was planted. Calculation of the amount of organic materials (that would give an equivalent of 60 kg N ha^{-1}) (Table 1) was ensured by the application of 1.3, 1.8 and 1.9 t ha^{-1} of tithonia, senna and calliandra, respectively. Half of this amount was applied to treatments that received a combination of organic and inorganic N fertilizers, giving 30 kg N ha^{-1}, while the remaining portion was obtained from urea. Application of urea was done following farmers' practice in two splits (20 kg ha^{-1} at planting and 40 kg ha^{-1} applied 5 weeks after planting). Since organic materials supply other macronutrients like phosphorus (P) and potassium (K) that ultimately affect maize yields (Jama et al. 2000), both nutrients were applied in all the plots during the first two seasons in non-limiting quantities (100 kg P ha^{-1} and 100 kg K ha^{-1}), to minimize the possibility of these confounding effects. This way, it was assumed that nitrogen (N) was the only macronutrient limiting maize yields.

Sampling and analyses

Maize harvesting

Maize was harvested from the net plots about 6 weeks before maturity for season 1 (due to poor rainfall distribution), while for seasons 2 and 3 harvesting was done at maturity. The harvesting area was determined separately for the three seasons. In the first season, harvesting was done on whole plots with two outer rows and two outer plants being left out to minimize edge effects. Thus, the harvesting area was 9.0 m^2 (out of the total area of 26.25 m^2). In the second and third seasons, one guard row on each side and two outer plants on each row were left out to eliminate edge effects. This gave a harvest area of 15.0 m^2.

During the second and third seasons, cobs in the harvested area were separated from the stover in the standing crop. The total fresh weight of the cobs was recorded. The stover was then cut at ground level, total fresh weight was taken, then a subsample was taken. To obtain the net grain yield, the grains were separated from the core by hand shelling; then each subsample was weighed separately. The fresh weight of the subsamples (stover, cobs and grain) was recorded, after which they were dried at 60 °C for about 3 days until a constant weight was attained.

Total yield was determined as follows:

$$\text{Yield (t/ha)}=[10\times(\text{TFW}\times\text{SSDW})]/(\text{HA}\times\text{SSFW})$$

where TFW is total fresh weight (kg); SSDW is subsample dry weight (g); HA is harvest area (m^2); and SSFW is sub-sample fresh weight (g).

After harvesting, all the maize stover was removed from the experimental plots to ensure that no nutrients were returned to the plots with the stover.

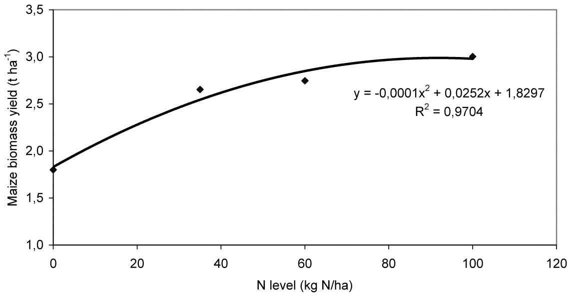

Figure 1. Maize biomass production response to levels of N during 1999 short rains season at NARL-Kabete, Kenya (maize biomass yields from the three organics were high above the response curve).

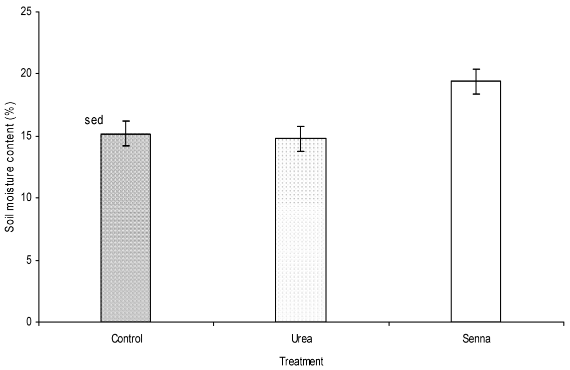

Figure 2. Soil moisture content as influenced by application of urea and senna at Kabete, Kenya in 2000.

Actual maize yields were reported as well as relative increase (Gachengo et al. 1999) while fertilizer responses (FR) of organic materials were obtained by comparing the yield from the organic material treatments to that of the nitrogen (N) response curve (Murwira et al. 2002). Since the response assumed a quadratic function with the equation $Y = a\mathrm{FR}^2 + b\mathrm{FR} + c$, the following formula for solving quadratic equations was used:

$$\mathrm{FR} = \frac{-b \pm \sqrt{(b^2 - 4ac)}}{2a}$$

where a, b, and c are constants which are obtainable from the quadratic equation of the response curve (Figures 1, 3 and 4). In order to compare the fertilizer equivalencies of organic materials, the fertilizer equivalency (FE) % values were calculated as follows:

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

where N applied is the actual amount of N applied. Source: Murwira et al. (2002).

Statistical analysis

Analysis of variance was conducted using the Genstat 5 for Windows (Release 4.1) computer package to compare the treatment effects on the parameters studied. Least-significant difference (LSD) in means was used for treatment comparison. Statistical significance refers to $\alpha \leq 0.05$. In determining the effect of the different organic materials, maize response to the organic inputs was calculated on the basis of yields obtained from urea alone at different rates. The interactive effect of the combined use of urea and organic inputs was determined by comparing maize yields obtained from the different combinations.

Results and discussion

Nitrogen fertilizer equivalencies of tithonia, calliandra and senna

Poor rainfall distribution during the first season (1999 short rains) resulted in a poor maize crop and so the harvesting of biomass was done 6 weeks before maturity, hence no grain yields were obtained. Nevertheless, the biomass production is important in these production systems since it serves as fodder. Maize biomass yields during this season were 3.3, 3.6 and 3.9 t ha^{-1} for calliandra, tithonia and senna treatments, respectively, compared to 2.7 t ha^{-1} from urea. All the organic inputs had a significant increase on maize biomass yield above the control (Figure 1). Only senna had significantly higher maize biomass yield than urea treatment. Maize biomass yield from the different organics did not differ significantly. As shown in Figure 1, the biomass yields obtained from the organics were higher than the biomass yields from any of the inorganic N source treatments, where the highest yield was 3.0 t ha^{-1} for 100 kg N ha^{-1} urea application. Thus, the values for the yields obtained from the three organic materials fell high above the N response curve. As a result, the fertilizer equivalencies for the organic materials for this season could

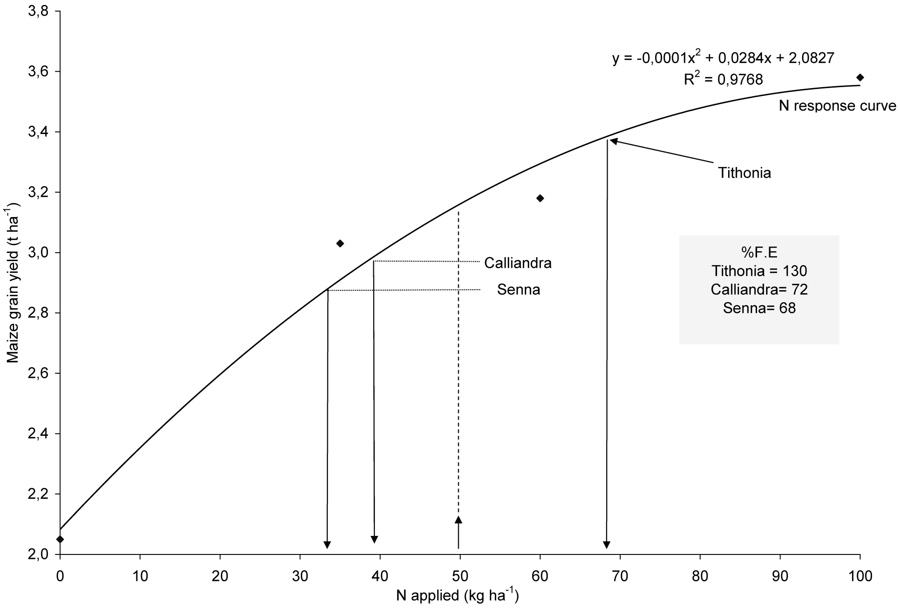

Figure 3. Season 2 (2000 long rains) maize grain yield production response to N levels and yields obtained with 60 kg N equivalent of organic amendments at NARL-Kabete.

not be estimated from the N response curve generated.

The differences in the biomass yields obtained from the organic and inorganic N sources may be due to the poor rainfall distribution during that growing season and the timing of the N application. Much of the rainfall was received in late November 1999 and early December 1999 and rainfall was scanty in January 2000. This was the tassling stage of the maize, hence the poor maize performance. Therefore, due to the mulching effect of the organic inputs, more moisture was possibly made available to the growing maize in the organic treatments, unlike in the inorganic treatments. The timing of application of the N from the organic versus the inorganic N sources may also explain the differences in yields. All the 60 kg N from the organics was applied at planting when there was adequate rainfall and moisture, while the urea was applied in splits (20 kg N at planting and 40 kg N applied 5 weeks after planting when there was no rain). This 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. As a result, 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 positive effects of the organic materials on soil physical and chemical properties. The water retention ability of the soil was enhanced by the organic material (Figure 2), in addition to added micronutrients (Chen and Avnimelech 1986; Wallace 1996; Murwira et al. 2002).

A better maize performance was observed during the second season in all treatments. Results obtained showed that maize grain yields from the organic treatments were 3.6, 3.1 and 3.0 t ha^{-1} for tithonia, calliandra and senna, respectively, compared to urea treatment of about 3.3 t ha^{-1} (all at the application rate of 60 kg N ha^{-1}; organics were applied at the beginning of the season all at once while urea was added in two splits) (Figure 3). This gave fertilizer equivalency values of 130% for tithonia, 72% for calliandra and 68% for 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 less compared to an equivalent amount of inorganic N source. The fact that decomposition rate and subsequent N release were higher in tithonia green biomass (Gachengo et al. 1999; Murwira et al. 2002) compared to senna and calliandra (Lehmann et al. 1995) could be a partial explanation for this phenomenon. Fertilizer equivalency values for tithonia and calliandra were almost twice the val-

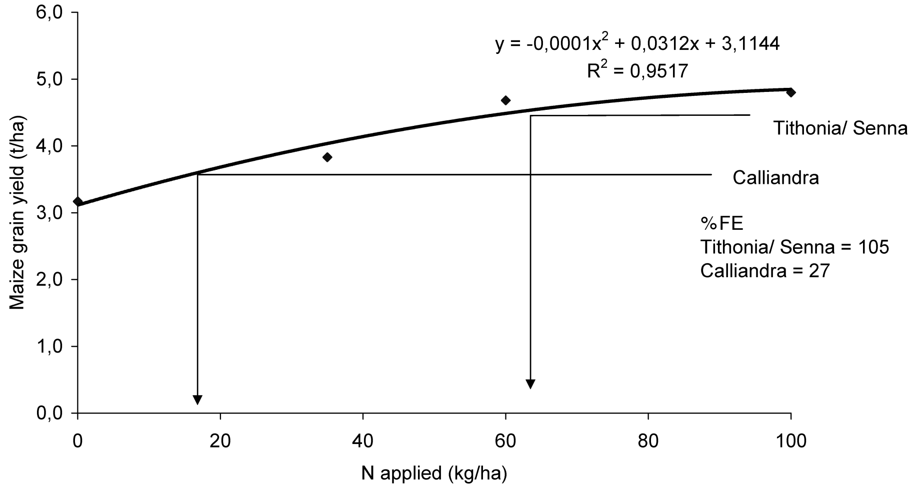

Figure 4. Residual fertilizer equivalency in season 3 (2000 short rains) at Kabete, Kenya (2001).

ues reported by Murwira et al. (2002) for the same organic materials in their trial in Western Kenya. This could be due to the difference in the climatic conditions at Kabete and Western Kenya, especially with regard to rainfall distribution during the growing seasons considered. The Central region (Kabete trial site) was characterized by poor rainfall distribution during the three seasons when this research was carried out. In circumstances of low precipitation, a better maize performance and subsequently higher fertilizer equivalency values could be expected from organic application. This could be due to other beneficial effects from the organic resources.

A residual influence of the different treatments on maize grain yield was investigated during the third cropping season. A fertilizer equivalency of 105% for tithonia and senna was obtained and 27% for calliandra (Figure 4). Averaging over the three seasons, calliandra, senna and tithonia had fertilizer equivalency values of 50, 87 and 118%. Lower maize biomass yields obtained from sole application of calliandra green biomass could be attributed to N immobilization during the previous season or reduced N release, as noted by Mwale et al. (2000a) in their study at Chalimbana, Zambia. Other researchers also observed that a 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). As indicated by Palm (1995), nutrient release patterns from organic materials are partly determined by their chemical composition or quality.

These results therefore suggest that tithonia green biomass may be recommended for direct application for soil fertility improvement. However, calliandra leaf biomass may not be recommended for direct application due to the high polyphenol content (11.1%) (as shown in Materials and methods) compared to the critical level of 4.0% (Palm et al. 2001) and also because of its low nitrogen content (2.4% N). This was clearly depicted by the low grain yield and fertilizer equivalency value of 50% obtained from calliandra treatment. 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 (Figure 5).

Effect of the combined organic and inorganic N sources on maize yield

Over the three seasons, it was also noted that maize grain yields from combined use of organic–inorganic N sources were dependent on the organic material used. As shown in Table 2, maize biomass yields were higher during the third season as compared to seasons 1 and 2. This could be due to the residue effect of the organic and inorganic amendments from the previous seasons.

The cumulative maize biomass yield for the three seasons was significantly different among the different treatments (Figure 5). Combining tithonia with urea increased maize biomass yields by about 7 tons above the control, while sole tithonia and urea applications increased yields by about 6 and 5 tons,

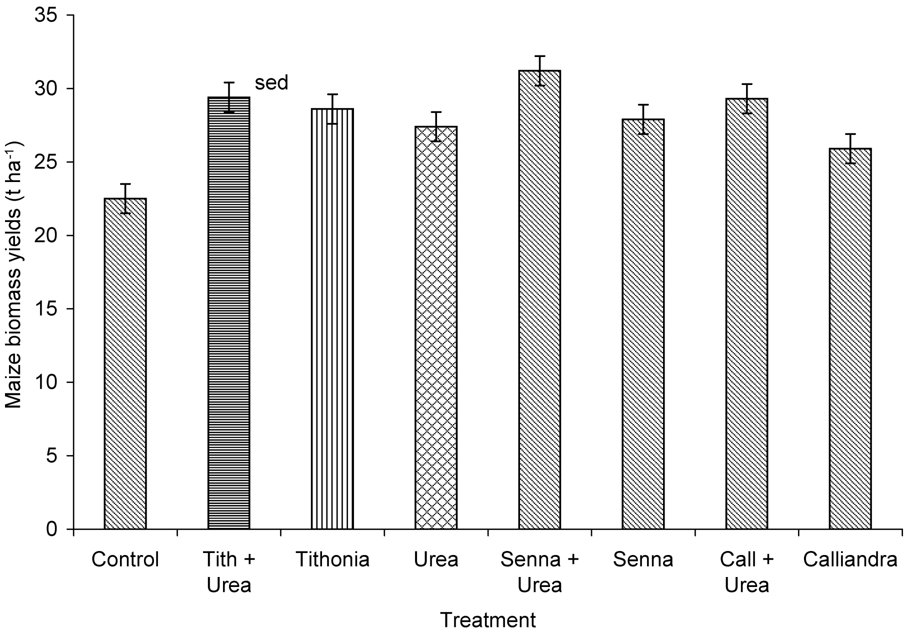

Figure 5. Effect of urea and different organics, sole application and in combination, on cumulated maize biomass yields at Kabete, Kenya over a period of three seasons (1999–2001).

Table 2. Maize grain and stover yields as influenced by combined organic and inorganic N sources at Kabete, Kenya within a period of three seasons (1999–2001) (no grain was harvested in the first (drought) season).

Treatment	Crop 1	Crop 2		Crop 3	
	Maize stover yield (t ha^{-1})	Stover (t ha^{-1})	Grain (t ha^{-1})	Stover (t ha^{-1})	Grain (t ha^{-1})
Control	1.8	7.0	2.1	8.4	3.2
Tithonia+urea	4.9	6.6	3.2	9.7	4.7
Tithonia	3.6	7.7	3.5	9.5	4.3
Senna+urea	5.1	9.2	3.1	9.2	4.6
Senna	4.1	6.9	3.0	8.9	4.7
Calliandra+urea	4.0	8.8	3.2	9.0	4.2
Calliandra	3.3	7.6	3.1	8.5	3.5
Urea	2.7	7.0	3.2	9.8	4.7
Sed	0.6	1.1	0.3	1.0	0.4

respectively (Figure 5). Senna combined with urea increased above ground maize biomass yields by more than 8 tons above the control. This is about 3 t ha^{-1} above the yield obtained with sole application of either. Though no significant difference was noted between maize biomass yield obtained from either sole application of calliandra or urea or a combination of both, calliandra+urea and urea treatments increased yields by about 7 and 5 tons, respectively, above control. Gachengo et al. (1999) also realized substantial maize yield increase in the use of combined inorganic fertilizer and either tithonia or senna leaf biomass.

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; Gachengo et al. 1999; Palm et al. 1997).

Other indirect benefits of organic materials to the soil may include improved moisture retention (Wallace 1996; Lehmann et al. 1999) and addition of micronutrients (Murwira et al. 2002). The availability of

C from the organics may prime the mineralization of N from soil organic matter and this adds to the available nitrogen for the growing crop. Addition of organics in the soil helps in reducing weed populations, hence reducing competition for added fertilizers, and this helps in improving the performance of the growing crop.

Conclusions

Average fertilizer equivalency values of 50, 87 and 118% for calliandra, senna and tithonia, respectively, were observed within a period of three growing seasons. This implied that tithonia green biomass performed better than an equivalent amount of inorganic fertilizer in improving maize biomass yields, while calliandra and senna performed relatively poorer. However, it was noted that 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 (polyphenol, lignin, nitrogen, phosphorus and potassium contents), soil moisture, and other nutrient effects from the biomass.

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. Similar research should be carried out for other organic materials and in different agroecological zones. Additionally, more research is needed to establish other specific beneficial effects of organic inputs on annual crop yields.

However, there are some limitations in the use of organics, which include: requirement of large quantities and associated labor demand; variable quality constraining the use predictability with respect to the Organic Resource Database (ORD) decision tree; little economic returns when the organics are not used on high value crops; and limited information about the right proportions of application.

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