Fertilizer nitrogen recovery as affected by soil organic matter status in two sites in Kenya

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Abstract

Management of nitrogen (N) nutrition is a vital aspect in maize production systems of Kenya. In Central and Western parts of Kenya, high population density has eliminated the use of traditional fallow farming systems for replenishing soil fertility while high unevenly distributed rainfall increase chances of N leaching. A study was conducted at Maseno, and Kabete to investigate the fate of fertilizer N in the soil-plant system using treatments that had been receiving leaf prunings of *Calliandra calothyrsus* and *Tithonia diversifolia* . Two microplots were installed in the main treatments to which labelled fertilizer was applied. At the beginning and at the end of 2002 long rains, soil was sampled to 200 cm for N and ^{15}N enrichment analysis at the two trials. Also at the end of the season plant samples were collected for N and ^{15}N analysis. At Maseno trial, evenly distributed rainfall and the influence of organic resource quality enhanced good fertilizer nitrogen recovery in the maize crop. Also substantial nitrate movement down the soil profile was observed in the control followed closely by calliandra at the end of the 2002 long rains season. At Kabete trial recorded the poorest fertilizer N recovery due to unevenly distributed rainfall. Limited soil moisture reduced both soil and fertilizer N uptake which was reflected in high N in the top soil and low recovery in plant. Most of the nitrate-N was left in the tp soil as a result of low rainfall which couldn't move it into the lower soil depths

Key words: Labelled fertilizer, mineral N, nitrate movement, microplots, nitrogen-15

Introduction

Effective management of nitrogen (N) presents a greater challenge to the farm operator than any other nutrient since it can enter or leave the soil-plant system by more routes than any other nutrient (Olson and Kurtz 1982). Nitrogen is the key to soil fertility and an essential component of soil organic matter (SOM), in fact, 90-95% of the total soil nitrogen (N) is associated or combined with the soil organic fraction (Andreux et al. 1990; Smith 1994). Therefore maintenance of an adequate soil nitrogen level goes hand in hand with maintenance of an adequate level of humus, which in turn determines many other factors related to soil fertility (Kang and Van der Heide 1985; National Research Council 1993).

Organic matter plays key roles in nutrient retention and availability, soil structure maintenance and water retention since it constitutes both a sink and a source of nutrients required by plants and ultimately by the human population (Craswell and Lefroy 2001; Merckx et al. 2001). Increasing the SOM content of soil is the key to building soil N capital (Buresh and Giller 1998). Nitrogen is the mineral element required in the greatest quantity by cereal crop plants and loss from a cropping system is a major source of agri-environmental pollution. Thus, N uptake and use by a maize crop is of fundamental importance to N economy in agricultural

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production (Ma and Dwyer 1998). The mineral-N may be unavailable to the crop if moved below the crop(s rooting depth by percolating water (Mugendi et al. 1999b).

Nitrogen fertilizer use efficiency (NFUE) is important due to environmental consequences of nitrate leaching (a global phenomenon) whose impact is recent in developing countries (de Vos et al. 2000; Rao and Rattanna 2000). It is therefore important to know to what extent nitrogen is recovered by the crop and whether nitrogen is left in the soil (Dilz 1988). Of importance to crops as shown by Mafongoya and Nair (1997) is accumulation of available N in the soil before the peak period of N uptake by maize which ensures synchrony between N supply and demand by the maize crop. Efficiency of N could be improved by 10-20% mostly due to an increase of about 16% in plant uptake of N (Isherwood 2000). On the other hand, organic resources play a critical role in both short-term nutrient availability and long-term maintenance of SOM in smallholder farming systems in the tropics (Palm et al. 2001).

To determine the movement of fertilizer N as affected by SOM status it is necessary to use ^{15}N-labelled fertilizer so as to distinguish between soil and fertilizer derived N (Bacon 1995; Hood 2001). Continued decline of soil fertility against the background of increasing rural poverty is threatening the smallholder farmer's long term food security and their source of livelihood. There is no doubt that the need to reverse decline in soil fertility is becoming critical. The challenge today is to find sustainable ways to increase agricultural growth at a rate faster than human population growth (Kamanga et al. 2000). This study therefore sought to determine (i) fertilizer N recovery in both plant components and top soil (ii) mineral N in the soil profile as affected by SOM status at three trials in Kenya.

Materials and methods

The study was conducted in two trials in Cental and Western Kenya. The Nitrogen Management (N1) at Kabete in Central Kenya is located at a longitude of 36° 46'E, latitude of 01° 15'S and an altitude of 1650 m above sea level. The site is located in the semi-humid climatic zone with a total bimodal rainfall of about 970 mm per annum received in two distinct rainy seasons; the long rains received mid March to June and the short rains received mid October to December. The soils are quartz trachyte geological material, and are typical Humic Nitisols, inherently fertile, with moderate amounts of C, Ca, Mg, and K but low in available P. Phosphorus management (PM1) experiment is located in the highlands of Western Kenya, on Msinde farm in Vihiga District. The experiment was established during the short rains of 1995 as Randomized complete Block Design (RCBD) with four replicates. The site is located at an altitude of 1420 m above sea level, latitude of 0° 06' N and a longitude of 34° 34' E. The mean annual rainfall is 1800 mm distributed in two distinct rainy seasons: long rains from March to August and short rains from September to January. The soil is a Nitisol according to FAO (1990) with 42% clay, 25% silt and 33% sand (Nziguheba 2001).

The ^{15}N experimental layout was a randomized complete block design (RCBD) with three replicates and maize (HB613) as the test crop. Two microplots measuring 3 by 1.25 m were established in each selected main plot. They were surrounded by 25 cm tall metal borders measuring 0.25 × 1.8 m which were inserted 15 cm into the soil with 10 cm remaining above the soil surface to prevent lateral movement of materials. Labelled ammonium sulphate (AS) was applied in microplots installed at planting and at knee height. The recovery of applied ^{15}N in the crop and soil was determined at the end of the cropping season. Maize was planted at an intrarow and interrow spacing of 0.25 and 0.75 m respectively.

Soil samples were sampled at planting and harvest from six depths (0-10, 10-30 30-60, 60-100, 100-150 and 150-200 cm) for moisture determination, N, and ^{15}N enrichment determination. Plant samples (ears and stover) were separated from a sampling area of 1.125 m^2 net plot of each microplot. Sub samples of six plants were chopped, their fresh weights taken, then oven dried at 60°C until weights stabilized, ground to pass through a 1 mm sieve. The harvested maize ears were also oven dried, shelled and cob and grain weighed separately.

A sub sample (1-6 mg) (pulverized stover, grain and cob) was weighed into tin capsules which were then analysed for total N and ^{15}N enrichment with an Automated Nitrogen and Carbon Analyzer–Mass Spectrometer (ANCA-MS). Total N and ^{15}N values obtained were later used in the determination of %N derived from fertilizer and % fertilizer N in the plant samples.

For determination of ammonium and nitrate, about 20 g of field moist soil was extracted with 100 ml of 2N KCl by shaking for 1 hour at 150 reciprocation per minute and subsequent gravity filtering with prewashed

Whatman No 5 paper. Soil water content was determined on stored field-moist soil at the time of extraction in order to calculate the dry weight of extracted soil. The extract was then analysed for extractable nitrate by Cadmium (Cd) reduction column and for extractable ammonium by salicylate-hypochrolite colorimetric method (Anderson and Ingram, 1993 and ICRAF, 1995). Soil water content was determined on the field moist soils at the time of extraction in order to calculate the dry weight of extracted soil. About 25-35 g of the soil sample was oven dried at 105°C for 24 hours after which sample dry weight was taken. The moisture content obtained was used in the calculation of mineral N (ammonium-N and nitrate-N) content in the soil that had been extracted with 100 ml 2N KCl as shown in the nitrate and ammonium formulae (Anderson and Ingram 1993; ICRAF 1995).

Statistical analysis

Data was analysed using GenStat for windows software (version 6.1, Rothamsted Experimental Station) (GenStat 2002). It was subjected to analysis of variance (ANOVA) for both within site and between sites variations. Treatment means found to be significantly different from each were separated by Least Significant Differences (LSD) and declared significant at P = 0.05 (Fisher, 1935). This was to determine relationships between SOM content and the movement of the applied fertilizer N in terms of crop uptake use efficiency and in relation to N application.

Results

Fertilizer nitrogen recovery in both plant and soil as affected by SOM status

At the end of the cropping season fertilizer N used by the crop and remaining in the soil organic forms was measured. Fertilizer N recovered in maize plant components (maize grain, cob and stover) and in soil profile (0-30 cm) at PM1 and N1 trials is presented in Table 1 and 2 respectively. At PM1 trial (Table 1), Maize grains had more ^{15}N compared to cob and stover in the L microplots. However, the ^{15}N for maize grain and cob was statistically insignificant ($P< 0.05$). In the UL microplots, grain had higher allocation of fertilizer N and in descending order the ^{15}N for maize grain was 27.4 > 26.7 > 17.3% for tithonia, calliandra and control treatments respectively whereby calliandra and

Table 1. Fertilizer ^{15}N recovery at PM1-Maseno trial, Kenya at the end of 2002 long rains

	Labelled first (L)				Labelled second (UL)			
	% fertilizer ^{15}N							
Variable	Calliandra	Tithonia	Control	Sed	Calliandra	Tithonia	Control	Sed
Grain	24.4	20.3	20.6	2.6	26.7	27.4	17.3	3.3
Cob	2.7	2.5	3.0	0.4	2.4	2.4	3.1	0.5
Stover	11.6	6.7	6.3	2.2	13.6	13.4	8.2	3.6
0-10 cm	22.7	17.6	20.8	1.5	24.0	21.0	21.3	2.9
10-20 cm	5.3	4.7	7.8	1.4	3.5	5.8	7.7	1.0
20-30 cm	3.9	3.1	5.7	1.4	3.4	3.1	3.9	0.6

Table 2. Fertilizer ^{15}N recovery at NI-Kabete trial at the end of 2002 long rains

	Labelled first (L)				Labelled second (UL)			
	% fertilizer ^{15}N							
Variable	Calliandra	Tithonia	Control	Sed	Calliandra	Tithonia	Control	Sed
Grain	3.8	6.7	2.4	2.3	0.5	0.5	1.2	0.5
Cob	0.5	1.2	0.7	0.4	0.0	0.1	0.1	0.1
Stover	20.8	19.5	22.7	7.1	3.1	2.0	1.9	1.4
0-10 cm	20.0	18.0	22.7	nd	91.5	93.1	94.6	8.0
10-20 cm	8.7	4.6	7.0	2.1	9.7	9.4	9.7	2.9
20-30 cm	4.5	3.0	3.6	1.0	3.1	1.2	4.2	1.6

tithonia treatments were significantly higher than the control. There was no significant difference in ^{15}N for cob and stover between the treatments.

Results from PM1 trial indicated that the amount of percent fertilizer in the 0-10 cm soil depth of the L microplots, was in the order of calliandra > control > tithonia, whereby in both depths calliandra treatment and control were significantly higher than tithonia treatment (Table 1). In 10-20 cm soil depth the order of percent fertilizer N was control > calliandra > tithonia whereby the control (7.8%) was significantly higher than tithonia treatment (4.7%). In 20-30 cm soil depths, percent fertilizer N was not significantly different between treatments.

At N1 trial (Table 2), in the L microplots recovery of % fertilizer ^{15}N in the maize components (maize grain, cob and stover) and in the various soil depths (0-30 cm) was not significantly different among the treatments (calliandra, tithonia and control). The same trend was observed in the UL microplots except the recovery of fertilizer N in soil 0-10 cm soil depth where control was significantly different from calliandra treatment. This is because there was a dry spell in this trial and a lot of fertilizer N was left in 0-10 cm soil depth especially in the UL microplots.

Inorganic nitrogen in the soil profile

Mineral N dynamics in the soil profile as affected by SOM status at the PM1 and N1 trials are presented in Figures 1 and 4 respectively. They present a comparison between mineral N in the soil profile at the beginning of the season (day zero) and at the end of the season

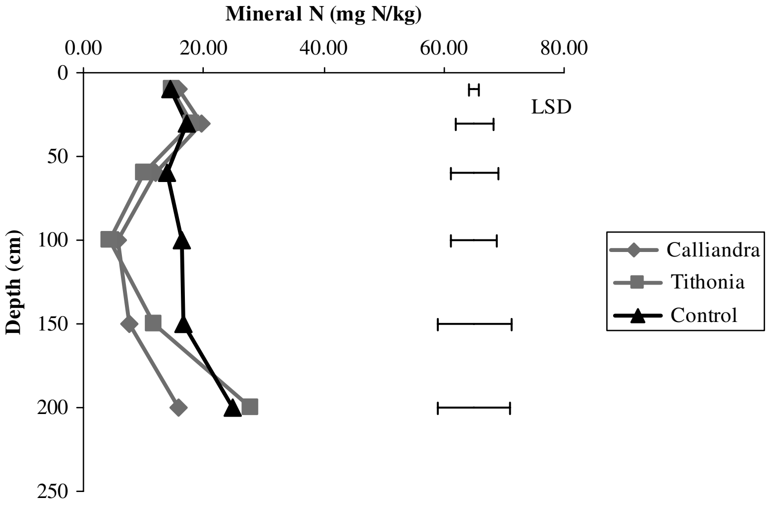

Figure 1. Mineral N status in the soil profile at the beginning of ^{15}N experiment at PM1-Maseno trial, Kenya.

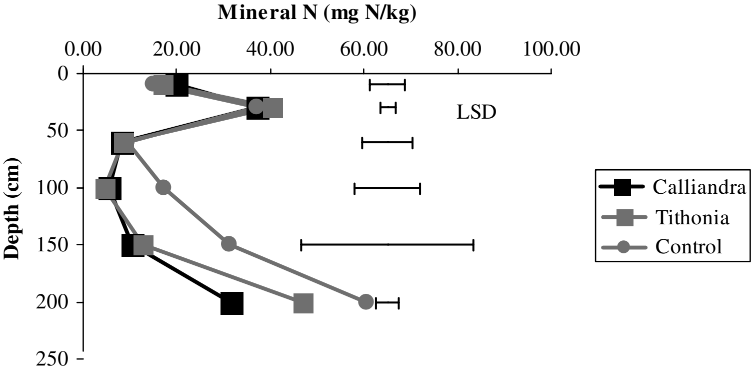

Figure 2. Mineral N in the soil profile at the end of 2002 long rains at PM1-Maseno trial, Kenya.

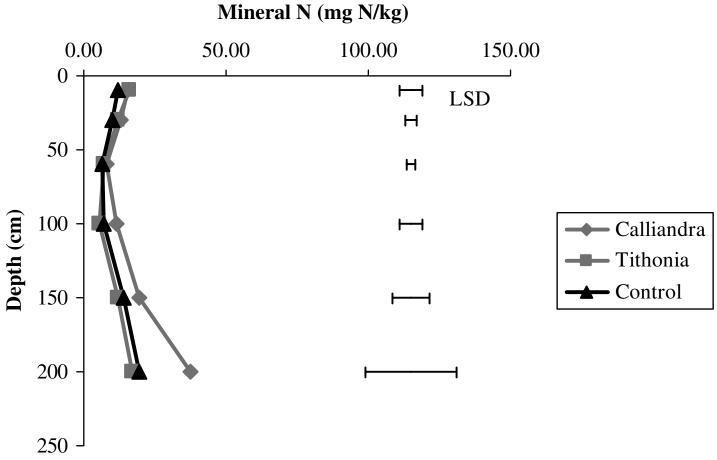

Figure 3. Mineral N status in the soil profile at the beginning of ^{15}N experiment at N1-Kabete trial, Kenya.

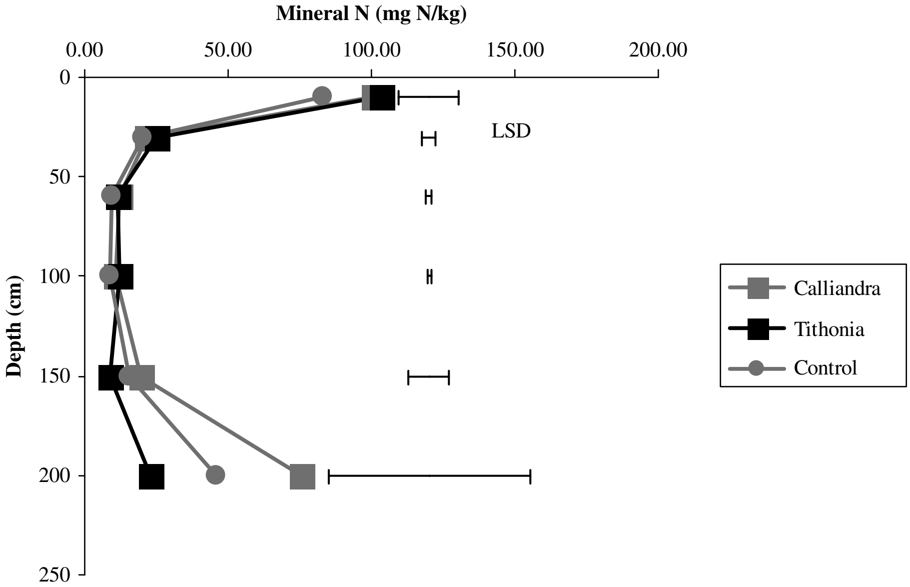

Figure 4. Mineral N in the soil profile at the end of 2002 long rains at N1-Kabete trial, Kenya.

(at harvest) which gives a picture of the extent of N movement down the soil profile at the two sampling times within a trial.

Results from PM1 trial (beginning of 2002 long rains) indicated no significant difference in the mineral N in soil depths 0-10, 10-30, 30-60, 100-150 and 150-200 cm (Figure 1). However, mineral N was significantly different for 60-100 cm soil depth with calliandra, tithonia and control recorded mineral N of 6, 4 and 16 mg N Kg^{-1}respectively. In this depth, amount of mineral N in control was significantly different from those in calliandra and tithonia treatments.

Amount of mineral N in the soil profile at the end of 2002 long rains at PM1 trial (Figure 2) in 0-10 cm soil depth was not significantly different between the treatments. In 10-30 cm soil depth, the amount of mineral N was in the order of tithonia > control > calliandra whereby tithonia treatment had 40 mg N kg^{-1} while calliandra and control each had 37 mg N Kg^{-1}. Again, amount of mineral N in the10-30, 30-60, 60-100 and 100-150 cm soil depths was not significantly different between the treatments. In 150-200 cm soil depth; the order was control > tithonia > calliandra whereby control (61 mg N Kg^{-1}) had significantly higher mineral

N than calliandra (32 mg N Kg^{-1}) and tithonia (47 mg N Kg^{-1}) treatments. Also tithonia treatment had significantly higher mineral N than calliandra treatment.

There was no significant difference in mineral N movement down the soil profile in N1 trial (Figure 3) despite its concentration in the top soil. Results from N1 trial (Figure 4), indicated that in 0-10 cm soil depth amount of mineral N was not significantly different among treatments. In the 10-30 cm soil depth, the amount of mineral N was in the order of tithonia > calliandra > control, whereby tithonia treatment (25 mg N Kg^{-1}) was significantly higher than the control (20 mg N Kg^{-1}). In 30-60 cm soil depth the order was calliandra > tithonia > control whereby calliandra (12 mg N kg^{-1}), tithonia (11 mg N Kg^{-1}) and control (9 mg N kg^{-1}) and were not significantly different. In 60-100 cm soil depth amount of mineral N was in the order of tithonia > calliandra > control whereby calliandra (11 mg N Kg^{-1}) and tithonia (12 mg N Kg^{-1}) treatments were significantly higher than the control (9 mg N Kg^{-1}). Also, results indicated that in 100-150 and 150-200 cm soil depths amounts of mineral N was not significantly different among treatments.

Discussion

At PM1 trial the ability of calliandra to build SOM could explain why this treatment had significantly higher ^{15}N recovery in the first fertilizer application. Haggar et al. (1993) reported that the build up of SOM reserve of mineralizable N is very important because it is from this reserve that N is made available to the crop. Also the high N accumulation in maize was probably due to rapid assimilation of nutrients by maize plants. Chirwa et al. (2004) observed high N accumulation in maize with fertilizer due to rapid assimilation. Higher enrichment on the other hand of ^{15}N in plants occurs when the applied labelled fertilizer N becomes effectively incorporated into soil organic matter (Cadisch et al., 1993). At this trial availability of water may have increased nitrogen mineralization in the soil thus increasing available N supply and uptake which was reflected in good fertilizer N recovery. These results tally with what was observed by Kamoni et al. (2003) with fertilizer application under irrigated conditions.

The poor recovery in the second application of the labelled fertilizer at the N1 trial in the maize crop components could be attributed to poorly distributed rainfall (Figure 5) which confirms what Kamoni et al. (2003) observed. Insufficient rainfall reduced crop N uptake and as a result most of fertilizer N was left in the top soil as was also observed by Hubbard and Jordan (1996) and in their study where sum totals of soil recoveries ranged from 33.62 - 79.14%. The ^{15}N concentration of plant components varied coinciding with findings by Ledgard et al. (1992). Since nitrogen transformations are intense in the root zone of crops under a broad range of conditions as noted by Atwell et al. (2002), inadequate water could have minimized these transformations leading to limited response of crops to fertilizer N and consequent low recoveries (Jama et al., 1995). The maize N recovery from applied N fertilizers was low (10-22%) (Okogun et al. 2000).

Ability of calliandra to build SOM in the soil could explain the high percent fertilizer N observed in 0-10 soil depth in calliandra treatment in the L microplots at PM1 trial. At 10-20 and 20-30 cm soil depths, a higher amount of fertilizer N was observed in the control. In the UL microplots, 10-20 cm soil depth control and tithonia had higher percent fertilizer N than calliandra treatment. Addition of labelled fertilizer N which was

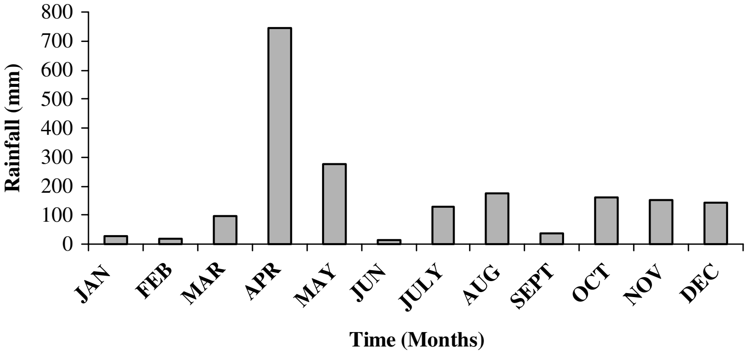

Figure 5. Rainfall at N1-Kabete trial in 2002 long rains.

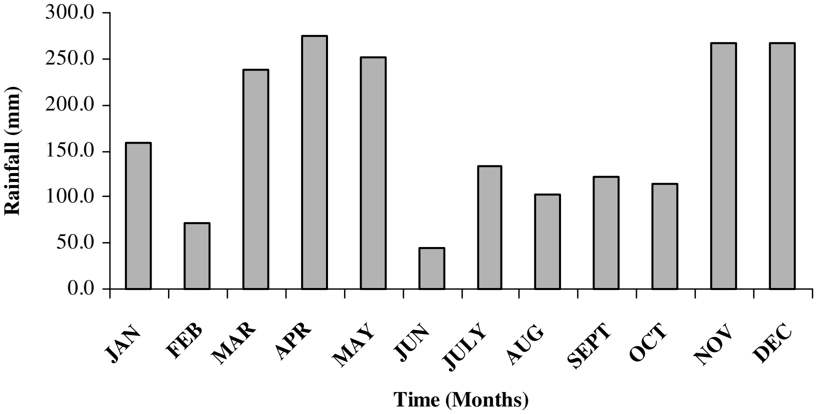

Figure 6. Rainfall at PM1-Maseno trial in 2002 long rains.

done even in the control explains why it had higher percent fertilizer N than the other treatments.On the other hand observations made at N1 trial in the L microplots, indicated that in the UL microplots, the 0-10 cm soil had percent fertilizer N ranging from 91.5 to 94.6%. Inadequate rainfall in this trial could have contributed significantly to poor crop uptake which was also observed by Kamoni et al. (2003) and as a result most of fertilizer N was left in the top soil. Inorganic fertilizer N is often readily immobilized into the organic pool of the soil such that a large proportion of fertilizer-N remaining in the soil at harvest was found in the plough layer. Water stress equally reduced the efficiency of N uptake.

Nitrate accumulation in the subsoil (30-200 cm) at PM1 trial concurs with the results found by Kindu et al. (1997); Mugendi et al. (2001) at 30-150 cm soil depth in a maize cropping system. Subsoil N accumulation could be attributed to greater N mineralization at the onset of the rainy season as well as high rainfall (Figure 6) that resulted in the subsequent nitrate movement down the soil profile. To avoid N loss through leaching Stenger et al. (1998) proposed that the inorganic N should be depleted during crop growth. The evidence of higher N movement in the control at this trial shows the importance of addition of organic residues and their SOM status improvement which is capable of minimizing N loss through leaching and enhancement of uptake and use efficiency of added fertilizer N. There was higher leaching in tithonia than in calliandra due to the differences in their resource quality (Xu et al., 1993). Poor resource quality residues (calliandra) are capable of building SOM as noted by Mafongoya and Nair (1993) and Mugendi et al. (2000) which is capable of minimizing N leaching.

Despite the concentration of mineral N at 0-10 cm soil layer at N1 trial, substantial N movement beyond the crop rooting depth occurred in both calliandra and control which could be attributed to the high rainfall intensity at the beginning of the experiment before the crop established a rooting system. Kimetu (2002) in his study carried out at N1-Kabete also found mineral N down the soil profile even up to 170 cm. Presence of mineral N at 100-200 cm soil layers arising from leaching tally with the findings of Budelman (1988) in his study. Amount of mineral N (top soil) at the end of the season indicates how much N was available to the crop but was not used nor lost from soil-plant system (Kimetu, 2002). Nitrate is easily leached as noted by Tisdale et al. (1993), and the leaching potential increases with increasing rainfall (Myers et al., 1994). However losses of N through denitrification and volatilization were assumed to be negligible in this study; soils were well aerated hence no loss by denitrification and the soil pH ranging from 5.1 to 5.4 was not high enough to facilitate the process of volatilization (Myers et al., 1994; Mugendi et al., 2003). On the other hand, amount of N in the lower soil depths represent what had been moved beyond the crop rooting zone and could not be recovered by the crop as a result of asynchrony (Kindu et al., 1997; Mugendi et al., 1999b). According to Myers et al. (1994), asynchrony is said to occur when the nutrients are released at a rate exceeding the uptake or slower than the plant needs which seemed to be the case at Embu trial. Results at this trial showed accumulation of nitrate-N in the lower depths suggesting a downward movement of nitrate-N from the top soil layers and an accumulation in the lower ones (Mugendi et al., 2003).

Conservation and maintenance of SOM is known to minimize leaching and concentrate N in the topsoil within the maize rooting zone. This is possible if organic resources used are of different quality which has a direct effect on mineralization and N release patterns (Xu et al., 1993). Also increased N-use efficiency as suggested by Becker et al. (1994a) will minimize opportunities for N loss (Myers et al., 1994). Slow N decomposition and an extended period with N immobilization may partially help reduce leaching (Thomsen and Christensen, 1998).

Conclusion

Crop response to nutrient applications depends on nature of the season especially rainfall amount and distribution. This was well demonstrated at PM1 trial where evenly distributed rainfall greatly contributed to increased crop yields. This was attributed to lack of moisture deficits which enhanced fertilizer N uptake leading to higher recoveries. Also SOM status as a result of resource quality especially in calliandra minimized N leaching and enhanced its uptake. Therefore, there was improved N uptake from both soil and applied fertilizer with evenly distributed rainfall at PM1 trail.

Nitrogen is only beneficial for increased N recovery if there is sufficient moisture. Addition of nitrogen during a poor season has been shown to lead to low recoveries. This was observed at N1 trial where poorly distributed rainfall caused soil moisture deficits leading to poor fertilizer N uptake and recoveries. A lot of mineral N was found in the plough layer due to lack of sufficient moisture to move it downwards. The same happened to organically bound N where so much was also left in the plough layer.

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