Effects of tillage on greenhouse gas emission and nitrogen mineralization under Tephrosia fallows in Nyabeda, Western Kenya

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Nitrogen availability was measured in two improved fallows (Tephrosia candida, Crotolaria paulina), natural fallows, and continuously cropped fertilized and unfertilized maize (Zea mays) in Nyabeda, Siaya District, Western Kenya. Nitrogen availability was high following incorporation of their residues. N availability in all the treatments declined over time during the cropping season indicating that the soil N capital is not adequate. Tillage did not significantly (P>0.05) affect N availability and gaseous emissions. No tillage, however, reduced total \(\text{N}_2\text{O}\) and \(\text{CO}_2\) emissions by 152 g N\(_2\)O-N ha\(^{-1}\) and 317 kg CO\(_2\)-C ha\(^{-1}\) respectively indicating its potential in reducing greenhouse effect. The findings of this study will be important in developing practices that increase N-use efficiency and reduce greenhouse gas emissions.

Key words: Tephrosia candida, Crotolaria paulina, tillage greenhouse gas emission and nitrogen mineralization.

Introduction

Because of the high incidences of soil fertility depletion in Western Kenya, improved fallow farming systems are being promoted for soil fertility improvements using nitrogen fixing trees/shrubs that are also capable of recycling of other nutrients through litter fall or pruning (Baggs \textit{et al.}, 2001). Despite these efforts, there are increasing concerns regarding low crop N recovery from added pruning (Giller and Cadisch, 1995) because of lack of synchrony between N release and crop demand, and the potential for substantial N losses (Baggs \textit{et al.}, 2001). Loss vectors in the field include nitrate leaching, erosion and gaseous emission (Mosier, 1998). The gaseous losses, as emphasized by recent research, are of particular concern due to their detrimental effect on the atmospheric environment. To date however, there are few reports of trace gas emissions from the tree-based tropical agricultural systems (Palm \textit{et al.}, 2002, Millar \textit{et al.}, 2003a). The effect of the various species pruning to the emissions of greenhouse gas is therefore necessary. Although Nair and Nair (2002), state that improved fallows have the potential for carbon sequestration, however, considerable effort is still required to assess the magnitude of this potential.

Many factors are involved in the regulation of nitrification and denitrification including climatic conditions, soil characteristics, and cropping practices and their interactions (Mills and Jones, 1996). Denitrification and nitrification processes are also linked to mineralization of SOM. Significant amount of soil organic N is mineralised during the growing season. Most crops require substantial quantity of N early in the growing season.
(Keeney, 1982). Traditionally nitrate has been the primary N form absorbed by plants due to rapid conversion of ammonium in the soil to the nitrate. Higher plants and microorganisms compete for N in soils. Since the microorganisms are more efficient in intercepting N, the availability of N for plant growth depends on the soil C: N ratio. When C: N>30:1, N is immobilized in the decomposition process of organic residue by soil microbes, while at 20:1<C: N<30:1, there is limited immobilization and release of N into soil environment occurs. Nitrogen is available for plant uptake at C: N<20:1 form (Mills and Jones, 1996).

In the study, N availability were measured prior to and following cutting of improved fallow species. Comparisons were made with natural fallow and continuous maize (fertilized and unfertilised) cropping systems. Knowledge of the contribution of these systems to atmospheric loading of greenhouse gasses will contribute to the development of appropriate organic matter management practices to mitigate emissions and to increase nutrient use efficiency in these systems. The beneficiaries will be the farmers whose crop yields would be improved with increased nutrient use efficiency. The mitigation of gaseous losses would also reduce global warming. The objective of this study was to determine N availability during the cropping season under different fallows and continuous farming systems as affected by chemical composition of the fallow residues and method of tillage.

Materials and methods

Study site

The field study was conducted in Western Kenya highlands at an existing KEFRI/ICRAF smallholder experimental farm at Nyabeda in Yala Division, Siaya District in Nyanza Province. The area lies on coordinates 0°07’N, 34°24’E at 1330 metres above see level (Soil Survey Staff, 1999). The area experiences bimodal rainfall pattern with two growing seasons. The first (long) rains season starts in March to July and the second (short) rain season starts from August to November. Annual rainfall ranges between 1500 to 1900-mm with an annual mean temperature of 24 °C (Rommelse, 2000). Despite the total high rainfall, dry spells occur during the growing seasons, negatively affecting crop production. The predominant soils in the area are P-sorbing alfisols and oxisol originally quite fertile but now quite depleted of N and P. Declining soil fertility has therefore been found as main factor limiting crop production (Hoekstra, 1988). The soils are silty clay loam, slightly acidic (pH 5.4) with low total cabon and N contents, and frequent P deficiencies (Nyambati, 2000).

The area is densely populated (500-1200 people Km$^{-2}$) with smallholder farms (0.2 – 2.5 Ha per household). Maize is preferred staple food and is often intercropped with beans, with low yields ranging between 700 -2000 Kg ha$^{-1}$ for maize and 100 - 500 Kg ha$^{-1}$ for beans. Other common food crops are bananas, cassava, sweet potatoes, sorghum, groundnuts, cowpeas and kales. In spite of the extreme land pressure, about 52 % of the farmers leave their farms under natural fallow (Swinkels et al., 1997), while others are increasingly adopting improved fallow farming systems (Sanchez et al., 1997).
Experimental treatments

Tillage and no-tillage practices were tested on *Tephrosia candida* fallow because of its ability to suppress weeds. The experiment was a randomized complete block design with three replicates comparing two treatments: *Tephrosia candida* (conventional till) and *Tephrosia candida* (no till). Each main plot measured 9 x 18m, and were subdivided into two equal sub-plots measuring (4.5 x 9m), where one of the sub-plots was either tilled or not tilled. The main plots were separated by 1m strips. *Tephrosia candida* had previously been seeded directly through intercropping into a growing maize crop. Fallows were harvested, and together with litter fall collected during fallow growth together, were incorporated by conventional till to 15cm depth or by no-tillage where residues remained on the surface three days later. Uniform broadcasts of inorganic P (Triple Superphosphate, 100 kg P ha$^{-1}$) and K (Muriate of Potash fertilizer, 100 kg K ha$^{-1}$) were also done over all the plots thereafter on 15-16 March 2002. Maize was planted at 53,333 plants per hectare over a period of three days from 16 – 18 March 2002. Emissions of N$_2$O, CO$_2$ and CH$_4$ were measured prior to and periodically following fallow biomass additions. This was done concurrently with estimates of available soil N. Measurements were made between February - June 2002.

Sampling was carried out before, and after harvesting mulch from the fallow tree species, land preparation and incorporation of mulch biomass into the soil. Gas sampling was then carried out 3, 6, 10, 13, 17, 24, 38, 60 and 88 days after mulch incorporation into the soil between February and June 2002. Nitrous, methane and carbon dioxide gases emitted from the soil were sampled using gas tight syringes into evacuated 12 ml gas vials from closed flux chambers (0.2 m height by 0.3m diameter) installed into the soil as described by Smith et al. (1995). Two chambers per plot (treatment) were inserted to a soil depth of 50 mm, 12 days prior to biomass incorporation. Care was taken during insertion to minimize disruption to the soil especially to soil inside the chambers. The chambers were reinstalled after biomass incorporation after which, they remained in situ until the end of the experiment. The chambers were closed for one hour before sampling.

In order to minimise effects of diurnal variation in gas emissions, all gas sampling was done between 10 am – 12.00 noon on each occasion (Baggs et al., 2000). The vials containing sampled gas were kept under refrigeration up to the time they were sent to Wye College in the United Kingdom for analysis using gas chromatography method. The gas samples were analysed for N$_2$O, CO$_2$ and CH$_4$ in an Agilent 6890 gas chromatograph fitted with an electron capture detector, flame ionisation detector and a methaniser. Column and detector temperatures were 50 and 250 °C, respectively. Gas chromatography using electron capture detector was used for N$_2$O analysis. The method is highly sensitive for N$_2$O analysis. Flame ionisation detector is highly sensitive and selective for organic gases and was used for the determination of CO$_2$ and CH$_4$.

Soil sampling and analysis

Bulk soil samples from six auger holes were taken at depth of 0 – 15cm at the same time of gas sampling for the purpose of determining gravimetric soil water contents. A sub sample of thoroughly was immediately put into a prewieghed and labeled moisture tins. This was used for determination of soil water content. A second sub sample of about 20 g was then collected from the remaining soil in the bucket and placed in a plastic bag, labeled
and sealed with sisal twine. The soil in the bags were analysed for mineral N and were stored in the refrigerator between collection and extraction (Dorich and Nelson, 1984).

During fallow growth, litter traps were installed in each fallow plot. These were used to quantify litter fall from each fallow treatment. Litter falls from the improved- and natural-fallow treatments were collected every two weeks for determination of chemical composition (or quality) and quantities of biomass incorporated. The fallow species were harvested at the onset of the long rains in March 2002. Harvesting was done between 1\textsuperscript{st} and 4\textsuperscript{th} March 2002. At fallow harvest the aboveground biomass was separated into woody biomass (main trunk and branches), foliage (leaves, small twigs) and pods. The woody material were removed from the plots and fresh weight of other plant components was determined and a sub sample taken to the laboratory for dry matter determination. The samples were oven dried at 40 °C for 72 hours. Dried sub samples were ground and passed through 20-mesh screen for further determination of chemical composition of residues.

Soil water content was determined gravimetrically. Fresh soil sample was weighed before being dried in an oven at 105 °C for 48 hours after which it was reweighed (Dorich and Nelson, 1984). Assessment of residue quality was done at Wye College in UK. Sub-samples of litter fall were analysed for dry-matter yield, total N and total C content using a C/N analyser coupled to a Europa 20/20 isotope ratio mass spectrometer. Lignin content was measured in an Ankom 220 fiber analyser. Total extractable polyphenol content were determined using Folin-Ciocalteu reagent in a method adapted from Anderson and Ingram (1993). All data was subjected to ANOVA using Genstat 5 Release 3.2 statistical program (p<0.05). Treatment means were separated using least significant differences test (LSD). Correlation of parameters were determined using excel data analysis tool.

**Results and discussion**

**Effect of tillage and non-tillage on greenhouse gas emissions and N release in soil**

**Daily fluxes**

Daily CO\textsubscript{2} and CH\textsubscript{4} fluxes did not differ significantly (P>0.05) between the treatments throughout the sampling period (Figure 1). Carbon dioxide and N\textsubscript{2}O fluxes were, however, generally higher in the tilled treatment while, CH\textsubscript{4} fluxes were higher in the non-tilled treatment. Nitrous oxide fluxes from no-till treatment were only higher than from tilled treatment on day 3 after residue incorporation. Carbon dioxide fluxes from no-tilled treatment were higher than those from tilled treatment on day 3, 10 and 24 after residue incorporation. Nitrous oxide and CO\textsubscript{2} fluxes peaked on day 10 after residue application in both treatments. Daily fluxes of CH\textsubscript{4} were negative from non-tilled treatment on day 6, 10, 60 and 88 after biomass addition while, were only were negative on day 60 and 88 from the tilled treatment (Fig. 1). This indicates that there was greater production than consumption of CH\textsubscript{4} in the non-tilled treatment.

**Total emissions**

There was no significant difference (P>0.05) between treatments in the amount of total N\textsubscript{2}O, CO\textsubscript{2} and CH\textsubscript{4} over 14, 28, 48, 60 and 88 days after incorporation of residues (Appendix 10a, 10b and 10c). Total N\textsubscript{2}O, CO\textsubscript{2} and CH\textsubscript{4} emitted over the sampling period
(99 days) were still not significantly different (P > 0.05) among the treatments. Higher total N\textsubscript{2}O emissions were measured from non-tilled than tilled \textit{Tephrosia} treatment over the first 14 days after residue incorporation; however, cumulative N\textsubscript{2}O emissions over 99 days were lower from non-till treatment (432 N\textsubscript{2}O-N Kg ha\textsuperscript{-1}) than from tilled treatment (584 N\textsubscript{2}O-N Kg ha\textsuperscript{-1}) (Appendix 10a). Higher cumulative CO\textsubscript{2} and CH\textsubscript{4} emissions were measured from tilled than from non-tilled \textit{Tephrosia} treatment throughout the sampling period. Cumulative CH\textsubscript{4} emissions reduced between 48\textsuperscript{th} up to 88\textsuperscript{th} day indicating greater consumption than production of CH\textsubscript{4} in these treatments (Fig. 2).

Fig. 1: Daily greenhouse gaseous emissions
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Effect of tillage and non-tillage on N release after biomass incorporation

There was no significant difference (P>0.05) in the amounts of available total N, NO$_3^-$ and NH$_4^+$ measured from tilled and untilled *Tephrosia* treatments throughout the sampling period (Figure 3). Total N measured was generally higher in the non-tilled treatment in the first 13 days after residue incorporation. Thereafter high total N was measured from tilled
treatment. The dominant forms of N measured from non-tilled and tilled treatments were \( \text{NH}_4^+ \) and \( \text{NO}_3^- \), respectively (Fig. 3).

![Graph A: Total N (NH$_4^+$-N and NO$_3^-$-N)](image)

![Graph B: NH$_4^+$ (5-15 soil depth)](image)

![Graph C: NO$_3^-$ (5-15 soil depth)](image)

**Fig. 3: Effects of tillage on nitrogen mineralization**
Total N measured in soils did not differ significantly (P>0.05) between the treatments throughout the days of observation except on 17th day after residue incorporation (Appendix 11a). On 17th day total N from tilled Tephrosia was the highest over the sampling period and it was significantly higher (P<0.05) than from Tephrosia no-till treatment (Appendix 11a). There was no significant difference (P>0.05) in the amounts of NO$_3^-$ in the tilled and non-tilled treatments throughout the experimental period (Appendix 11b). Tilled treatment had significantly higher (P<0.05) NH$_4^+$ amounts only on day 3 and 6 after residue incorporation (Appendix 11c). Generally higher total N, NO$_3^-$ and NH$_4^+$ were measured from tilled than non-tilled treatment (Fig. 10). Nitrogen release at 5-15cm depth was also generally higher than from 0-5cm in both treatments.

Effect of tillage on gaseous emissions

Aulakh et al. (1991), found that surface-placed residues resulted in lower initial rates of denitrification. This is in contrast with the results of this study where N$_2$O fluxes from no-till treatment were higher than from tilled treatment on day 3 after residue incorporation. Denitrification potential and rates in soils are controlled by amount of NO$_3^-$ and C susceptible to mineralization (Aulakh et al., 1991). Tillage accelerates decomposition of SOM with consequent increases in both available SOC and nitrate, which enhances denitrification. Tillage also temporary lowers soil moisture content, which affects decomposition rates and anaerobic state of soil (Li et al., 1994). Available NO$_3^-$ was higher and dominant N form in the tilled treatment thus enhancing denitrification potential and hence increased N$_2$O emissions. Higher available NO$_3^-$ resulted from increased rate of nitrification. Nitrification is the biological oxidation of ammonia to nitrate. The process requires molecular oxygen and hence would readily take place in well-aerated soils in the tilled treatment (Tisdale and Nelson, 1975).

In well-drained neutral to slightly acid soils the rate of oxidation of NO$_2^-$ to NO$_3^-$ is higher than NH$_4^+$ to NO$_2^-$. If the rate of NO$_2^-$ formation is equal to or greater than that of NH$_4^+$, nitrate is the form that therefore accumulates (Tisdale and Nelson, 1975). The results of the study agree with this since NO$_3^-$ was the dominant form of N in the tilled treatment. Higher initial CO$_2$ fluxes from non-tilled treatment could have occurred due to activity of soil microbes, which probably were disturbed on the tilled treatment. A significant proportion of soil microbial biomass may be directly killed by soil disturbances. Microbial activity was, however, short lived. Aulakh et al. (1991) also found that with surface placed residues initial CO$_2$ production was greater than corresponding incorporated residue treatments due to the activity of epiphytic fungi, while denitrification rates showed an opposite trend.

Methane (CH$_4$) fluxes were generally higher from non-tilled than tilled treatment, probably due to enhanced anaerobic conditions in the non-tilled treatment. In the non-tilled treatment, CH$_4$ may have been microbially produced through methanogenesis process. The major pathways of CH$_4$ production in anaerobic conditions involve: (i) the reduction of CO$_2$, with H$_2$, fatty acids, or alcohols being the hydrogen donors; and (ii) the transmethylation of acetic acid or methyl alcohols by methane-producing bacteria (Verchot et al., 2004). In the tilled treatment where aerobic conditions were enhanced, CH$_4$ may have been oxidised by bacteria through methanotrophy process. Methanotrophy is a biochemical process, which is dominant in aerobic soils or upland soils. In these soils, oxidation
generally exceeds production and there is a net uptake by the soil of CH$_4$ atmosphere (Verchot et al., 2004).

Initial higher emissions in the non-tilled treatment could have been due to N$_2$O produced near the surface diffusing readily out of the soil into the atmosphere, where as N$_2$O produced after cultivation, may have taken longer to diffuse from the soil providing more opportunity for reduction to N$_2$, before reaching the atmosphere (Arah et al., 1991). N$_2$O emissions from the study contrasts emissions of N$_2$O from the temperate systems that have been generally reported to be higher from undisturbed, no till, than from cultivated soils (Baggs et al., 2002).

Higher initial CO$_2$ emissions in the tilled treatment could have been caused by immediate creation of anaerobic conditions conducive for denitrification and methanogenesis under the residues by increased water content (Aulakh et al., 1991). Anaerobic conditions enhance anaerobic decomposition, which leads to the formation of methane and carbon dioxide gases (Tan, 1994). Thereafter the aerobic conditions in the tilled treatment lead to the oxidation of CH$_4$ to CO$_2$. Higher CH$_4$ emissions could have been produced microbially in the anaerobic conditions under no-tilled treatment. Microbial oxidation of CH$_4$ to CO$_2$ was very likely reduced by anaerobic conditions in the non-tilled treatment and hence increased accumulation of CH$_4$. The margins between CH$_4$ emissions from non-tilled and tilled treatment were higher between 28$^{th}$ and 60$^{th}$ day. This could have been caused by higher rainfall (445mm) experienced during this period, which enhanced anaerobic conditions in the non-tilled treatment and hence reduced oxidation of CH$_4$ to CO$_2$.

No-tillage of Tephrosia resulted in an estimated reduction in emissions of 919 g N$_2$O-Nha$^{-1}$yr$^{-1}$ and 318 Kg CO$_2$-Cha$^{-1}$yr$^{-1}$ and increased CH$_4$ emissions of 144 g CH$_4$-Cha$^{-1}$yr$^{-1}$. Chikowo et al. (2003) also measured lower N$_2$O emission from non-tilled than from tilled Sesbania residues over four weeks in an improved fallow system in Zimbabwe. Although tillage increased emissions of N$_2$O and CO$_2$ there was no significant difference between tillage and no-tillage practices. This may have been due to the fact that the no-till treatment had not been established long enough to cause significant accumulation of organic matter on the soil surface (Six et al., 2002). Similarly Millar, (2002) found no significant effect of tillage following application of Macroptilium atropurpureum residues to an oxisol in Western Kenya. Aulakh et al. (1991) also found that cumulative CO$_2$ and N$_2$O losses were not significantly different with respect to crop residue placement.

Effects of tillage effect on N release

Tilled treatment had generally higher NO$_3^-$-N pools at 0-5 cm soil depth compared with non-tilled treatment. This indicates that net nitrification rates were higher in the tilled treatment, which resulted in higher cumulative N$_2$O emissions. The results of the study are in agreement with findings of Neill et al. (1995), that depth affects the net nitrification rates and these rates are higher at 0-5 cm depth. On the other hand, the soil NH$_4^+$ remained relatively high at soil depth 0–5 cm for non-tilled treatment, which indicates that nitrification potential was low and hence reduced denitrification potential. In 5-15 cm depth there was no dominant form of mineral N in the tilled treatment, which indicates that net mineralization and nitrification were more or less equal. In the no-till treatment NH$_4^+$ form dominated. This resulted from reduced soil aeration, which reduced nitrification potential. Nitrification normally takes place under oxygenated conditions.
In the study, tillage did not affect significantly nitrogen availability both at 0-5 and 5-15 cm depth; however, N levels were generally higher at 5 –15 cm soil depth. At 15 cm higher N availability was most likely due to reduced denitrifier activity. Soil organic matter, especially easily decomposable fraction, is an important source of soluble carbon and nitrate for denitrification (Li et al., 1994). As fertilizers are applied deeper into the soil, they become less available to denitrifying bacteria, which are active near the surface where carbon substrate is more abundant and saturated conditions are more frequent.

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References


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