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A short-term investigation of trace gas emissions following tillage and no-tillage of agroforestry residues in western Kenya

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Abstract

Improved-fallow agroforestry systems are increasingly being adopted in the humid tropics for soil fertility management. However, there is little information on trace gas emissions after residue application in these systems, or on the effect of tillage practice on emissions from tropical agricultural systems. Here, we report a short-term experiment in which the effects of tillage practice (no-tillage versus tillage to 15 cm depth) and residue quality on emissions of N_2O, CO_2 and CH_4 were determined in an improved-fallow agroforestry system in western Kenya. Emissions were increased following tillage of *Tephrosia candida* (2.1 g N_2O-N ha^{-1} kg N $applied^{-1}$; 759 kg CO_2-C ha^{-1} t C $applied^{-1}$; 30 g CH_4-C ha^{-1} t C $applied^{-1}$) and *Crotalaria paulina* residues (2.8 g N_2O-N ha^{-1} kg N $applied^{-1}$; 967 kg CO_2-C ha^{-1} t C $applied^{-1}$; 146 g CH_4-C ha^{-1} t C $applied^{-1}$) and were higher than from tillage of natural-fallow residues (1.0 g N_2O-N ha^{-1} kg N $applied^{-1}$; 432 kg CO_2-C ha^{-1} t C $applied^{-1}$; 14.7 g CH_4-C ha^{-1} t C $applied^{-1}$) or from continuous maize cropping systems. Emissions from these fallow treatments were positively correlated with residue N content ($r = 0.62$–0.97; $P < 0.05$) and negatively correlated with residue lignin content ($r = -0.56$, N_2O; $r = -0.92$, CH_4; $P < 0.05$). No-tillage of surface applied *Tephrosia* residues lowered the total N_2O and CO_2 emitted over 99 days by 0.33 g N_2O-N ha^{-1} kg N $applied^{-1}$ and 124 kg CO_2-C ha^{-1} t C $applied^{-1}$, respectively; estimated to provide a reduction in global warming potential of 41 g CO_2 equivalents. However, emissions were increased from this treatment over the first 2 weeks. The responses to tillage practice and residue quality reported here need to be verified in longer term experiments before they can be used to suggest mitigation strategies appropriate for all three greenhouse gases.

Keywords: Agroforestry residues; Carbon dioxide; Methane; Nitrous oxide; No-till; Residue quality

1. Introduction

There are few reports of trace gas emissions from humid tropical agroforestry systems, in which tree prunings or residues are returned to soil to maintain fertility and supply nutrients for subsequent crops (Palm et al., 2002; Chikowo et al., 2004; Millar et al., 2004). In improved-fallow agroforestry systems, fast growing legume tree or herbaceous species are grown in a crop-fallow rotation, and the tree residues are applied to soil prior to subsequent crop growth to improve soil fertility and alleviate N deficiency (Sanchez, 1999). N_2O and CO_2 emissions are typically increased after addition of

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residues, since organic material is often readily decomposed and N_2O subsequently produced during nitrification and denitrification (Baggs et al., 2000). The quantity of N_2O emitted after incorporation of agroforestry residues was positively correlated with residue N content under field conditions (Millar et al., 2004), but more strongly negatively correlated with residue polyphenol content under controlled environment conditions (Baggs et al., 2001; Millar and Baggs, 2004). The influence of residue quality on CO_2 and CH_4 emissions or the effect of no-tillage on trace gas emissions have yet to be determined in tropical agroforestry systems, although the mechanisms controlling trace gas production and consumption may be expected to be the same in tropical as in temperate systems. Here, we report a short-term experiment in which N_2O, CO_2 and CH_4 emissions were measured following addition of residues in an improved-fallow agroforestry system in western Kenya. We hypothesised that addition of high N improved-fallow residues would increase trace gas emissions, and that no-tillage of these residues would further increase N_2O emissions, but lower CO_2 and CH_4 emissions compared with conventional tillage.

2. Materials and methods

A randomised block design was established on a smallholder farm at Nyabeda, western Kenya Highlands (0°07′N, 34°24′E, 1330 masl, annual mean temperature 24 °C, bimodal mean annual rainfall 1800 mm) from February to June 2002 during the long-rains season. Soil was a free draining silty clay loam (25% sand, 55% silt, 20% clay, 5.9 pH (H_2O), 1.3% total C, 0.12% total N, 1.6 mg extractable P kg^{-1}, 1.13 g cm^{-3} bulk density) classified as a very fine kaolinitic, isohyperthermic Kandiudalfic Eutrodox (Soil Survey Staff, 1999) or a Ferralsol (FAO classification). The site had previously been cultivated with maize (*Zea mays* L.) with periodic fallowing of naturally regrowing species.

The fallow species *Tephrosia candida* (white hoary pea) and *Crotalaria paulina* (rattlebox) had been direct seeded into a growing maize crop in April 2001. A natural-fallow treatment was established in which natural vegetation, *Digitaria abyssibica*, *Habiscus cannabinus*, *Bidens pilosa*, *Guizotia scabra*, *Leonotis nepetifolia* and *Commelina benghalensis*, was allowed to regenerate. The fallow species were harvested at the onset of the long-rains in March 2002, woody material removed and the remainder uniformly spread over plots (50 m^2). Comparisons were made with plots under continuous cropped fertilized (100 kg N ha^{-1} $year^{-1}$ as urea) and unfertilized maize to which no fallow residues had been applied. Residues and fertilizer were subject to tillage to 15 cm depth, or no-tillage where residues remained spread over the soil surface. Maize was planted in all treatments (53,000 plants ha^{-1}) over a 4 day period between 8 and 11 March 2002. Each treatment was replicated four times. Prior to their application, sub-samples of residues 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 (Table 1). Lignin content was measured in an Ankom 220 fiber analyser. Total extractable polyphenol content was determined using Folin–Ciocalteu reagent (Anderson and Ingram, 1993).

Gas samples (three replicates per plot) were taken from closed flux chambers (0.2 m height by 0.3 m diameter) using gas-tight syringes. Sampling was undertaken on days 1, 8 and 14 after no-tillage of the continuous maize soil, *Crotalaria* and natural-fallow residues, and on days 1, 8, 14, 16, 20, 23, 27, 34, 46, 70 and 99 after no-tillage of *Tephrosia* residues and tillage of the continuous maize soil, *Crotalaria*, *Tephrosia* and natural-fallow residues. Chambers were closed for 1 h during gas sampling. Samples were taken at 20, 40 and 60 min after chamber closure and the linearity of gas diffusion into the headspace over this closure period was determined so that a daily flux could be calculated. Samples were analysed for N_2O, 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 50 and 250 °C, respectively). Total emissions were calculated by linear interpolation between daily fluxes. The global warming potential (GWP) of treatments was calculated based on the N_2O, CO_2 and net CH_4 emissions measured over 99 days after residue addition, taking the per molecule GWP of N_2O and CH_4 relative to CO_2 as 310 and 15, respectively. However, these calculations assumed no temporal variability in emissions beyond

Table 1
Biomass applied and chemical composition of improved- and natural-fallow residues

Treatment	Biomass applied (t ha^{-1})	N (%)	C:N	ADL[a] (%)	TEP[b] (%)
Tephrosia candida	7.4	3.6	11	15.6	1.7
Crotalaria paulina	5.0	3.7	11	13.5	3.7
Natural-fallow	10.7	1.1	36	14.7	0.8

[a] Acid detergent lignin.
[b] Total extractable polyphenols.