Initial Nitrous Oxide Fluxes from a Maize–legume Cropping System in a Soil of the Derived Savanna Zone of Nigeria– Effect of Fertilizer and Incorporated Organic Matter

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Abstract

Legume–maize crop rotations are used as a mechanism to reverse declining soil fertility in West Africa. However, such crop rotations exhibit a relatively low recovery of legume N. Temperate region studies partly attribute low N recovery to gaseous N losses, but this has not been established for most cropping systems in the moist tropical savannas. The effect of incorporating added organic residues and fertilizer application on gaseous N_2O fluxes was studied in a field trial at the International Institute of Tropical Agriculture (IITA), Ibadan (7 °30′N, 3 °54′E) in the derived savanna zone of Nigeria. Gaseous N_2O fluxes were obtained 1, 3, 5, 8, and 15 days after incorporation of organic residues using a vented closed chamber system. Fluxes were examined in relation to soil mineral N status and rainfall patterns. Fertilizer application and incorporation of *Pueraria phaseoloides* organic residue increased soil mineral N contents as well as gaseous N_2O fluxes. Over the 15-day period, the total N_2O fluxes were in the range of 21–30 mg N m^2 for *P. phaseoloides* and 12–15 mg N m^2 for natural fallow. Fertilizer-derived N_2O fluxes were less than 1% of applied fertilizer N.

Introduction

In sub-Saharan Africa, increased pressure on agricultural land due to population increases has led to shortened fallow periods. Intensified cropping of these typically nutrient-poor ferric Lixisol soils has resulted in decreasing yields in farming systems with low-external inputs, increased soil acidification, and a general decline in soil fertility. The use of N-fixing legumes in rotation with maize is a promising technology for reversing this decline and nitrogen fertilizer replacement values between 50 and 120 kg have been reported for different legumes (Tian *et al.*, 2000, Schulz *et al.*, 2001).

Although biological N-fixation legumes in the tropics can fix up to 300 kg N ha^{-1} (Sanginga *et al.*, 2001, Tian *et al.*, 2001; Carsky *et al.*, 2001; Giller, 2001), only 10–30 % of the legume N is recovered in such rotations and losses are attributed to erosion, leaching, and gaseous losses (Giller *et al.*, 1995). Temperate region studies suggest annual gaseous N losses of up to 32 kg N ha^{-1} from grasslands and arable soils under varying N input levels (Vermoesen *et al.*, 1996; Goossens *et al.*, 2000).

Gaseous N fluxes from tropical agricultural systems are receiving increasing attention not only due to their influence on global warming

TABLE 1
Basic site soil characteristics (0–30cm).

pH_{aq}	C (%)	N (%)	P (ppm)	ECEC (cmol kg^{-1})
5.3 (0.1)	0.68 (0.03)	0.09 (0.002)	25 (4)	4.4 (0.3)

Numbers in brackets indicate standard errors of the mean.

but also due to the potential loss of plant available N. Nitrous oxide (N_2O), a greenhouse gas with a global warming potential 310 times that of CO_2, is formed during the soil processes of nitrification and denitrification. In addition, rhizobia bacteria, which live in symbiosis with leguminous plants, also have the ability to denitrify N to N_2O. Atmospheric concentration of N_2O is increasing at an annual rate of 0.2 % (Rodhe, 1990) and it is estimated that the intensification of tropical agricultural systems will further increase the concentration of N_2O in the atmosphere (Erickson and Keller, 1997).

Factors affecting N_2O emissions are unclear but emissions generally increase with increasing soil acidification (Sahrawat and Keeney, 1986), increasing temperature (Granli and Böckman, 1995), and soil moisture and nitrate availability (Weitz *et al.*, 2001). The addition of fertilizer N, or easily decomposable organic matter with high N contents increases emissions (Larsson *et al.*, 1998; Khalil *et al.*, 2002). Emission peaks for N_2O occur shortly after the addition of fertilizer or organic matter (Larsson *et al.*, 1998; Weitz *et al.*, 2001), within 24 hours after rainfall events (Dick *et al.*, 2001) and are associated with soil moisture contents (Weitz *et al.*, 2001; Khalil *et al.*, 2002). Few have investigated the emissions from agricultural systems where organic residue (OR) is added. Aspects of organic matter (OM) quality such as N content (Larsson *et al.*, 1998) and lignin and polyphenol contents (Baggs *et al.*, 2002) influence emissions, as does OR placement and tillage. Baggs (2002) found that emissions from no-till systems where crop residue was applied as mulch were seven times greater than from conventionally tilled systems.

IITA has developed technologies involving the use of herbaceous or dual-purpose grain legumes, either as cover crops, mulches or improved fallows, in order to increase N retention and the agricultural sustainability of such a system. The question of N_2O fluxes from such systems and their effect is yet to be answered.

In this study we report the N_2O emissions up to 15 days after maize planting in a legume–maize crop rotation in subhumid Nigeria. The objectives of the study were to assess the effects of incorporating added leguminous OR and application of fertilizer.

Materials and methods

Site

A field trial was established in May 2000 at IITA, Ibadan, Nigeria (7 °30′ N, 3 °54′ E), on a ferric Lixisol (FAO, 1991). Previous to trial establishment, the land had been fallowed for 2 years, before which the site had been used for seed production. The site is characterized by low soil nutrient status (Table 1). Mean annual rainfall in the area is 1200 mm and is distributed bimodally with a dry season from November to March (Fig. 1).

Fallow legume species, establishment, and placement

The legume was selected on the basis of its potential as an improved dry season fallow. Biomass production, drought tolerance, and grain yield were taken into consideration. Natural fallow served as the control.

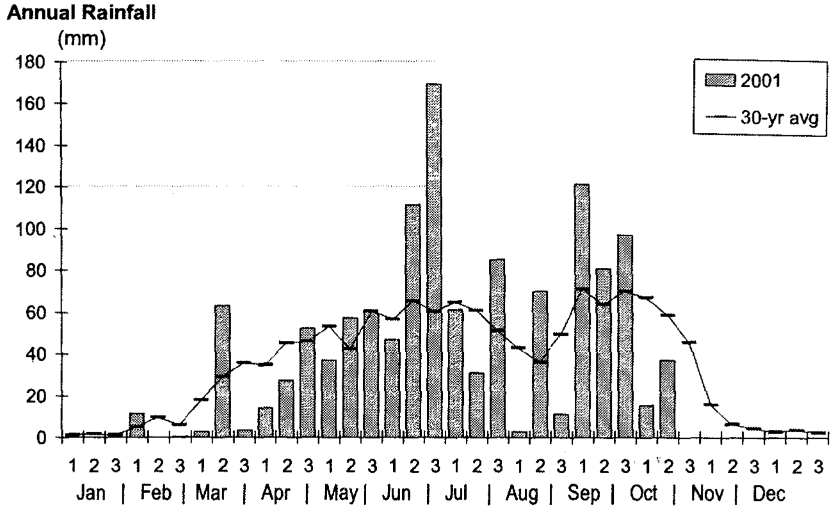

Figure 1. Rainfall distribution. Rainfall data are displayed as accumulated rainfall over 10 days, approximately three times per month, as denoted by 1, 2. and 3.

Maize was planted after fallow was cleared in May 2000 in rows of 0.75 x 0.25 m. *Pueraria phaseoloides* was relay cropped intermittently with maize, on plots of 8 x 9 m each in a split-plot design with three replicates. Net plot size was 6. 25 x 5 m.

The maize was harvested at the end of the rainy season in September 2000. All biomass was removed. The plots were hand weeded regularly until the start of the next rainy season started in June 2001, when the fallow and *P. phaseoloides* OR was incorporated manually, using the traditional hoe. The next maize crop was planted directly after incorporation of the OR in rows of 0.75x 0.25 m. Urea fertilizer was broadcast at two levels (0 and 15 kg N ha^{-1}) at the time of planting. Weeding was undertaken regularly.

Gas sampling

Gaseous N_2O fluxes were obtained 1, 3, 5, 8 and 15 days after maize planting and incorporation of the fallow and legume OR, using a vented closed chamber system (Hutchinson and Mosier, 1981), with two replicates per plot. Sampling continued every 4 weeks until harvest, but only the results from days 1 to 15 are presented here. Sampling of N_2O fluxes started at 9 am every sampling day. The chambers were inserted 5 cm into the soil, and gas samples were taken at time 0 (background), 30, and 60 min.

Analysis

Fallow OR was analysed for N, lignin and polyphenol content (Novozamsky *et al.*, 1983; Anderson & Ingram, 1993). Soil (0–30 cm) was sampled 0 and 15 days after OM incorporation and analysed for mineral N (Kalra & Maynard, 1991) and gravimetric moisture content (ISRIC, 1993).

Gas samples were analysed for N_2O contents on a Shimadzu 14B ECD gas chromatograph fitted with an electron capture detector. Rainfall was monitored daily throughout the study period. A schematic presentation of events and rainfall during the study is given in Fig. 2.

Statistical analysis

Statistical analysis of variance was performed using SAS PROC MIXED at 5% level of significance (SAS Institute, 1999).

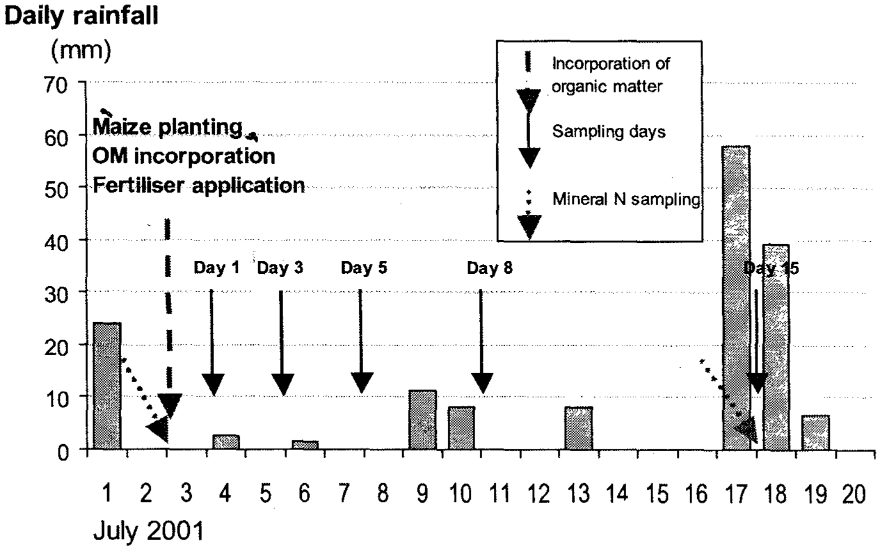

Figure 2. Field activities and rainfall pattern during the study.

Results

The plant OR contained 1.9-2.3 % N, 9-10 % lignin and 0.4-3.3 % polyphenol, and contributed 52 kg N ha^{-1} (natural fallow) and 148 kg N ha^{-1} (*P. phaseoloides*) (Table 2). Temperatures on sampling days ranged between 27 and 33° C in the air and between 27 and 31°C in the soil while the gravimetric soil water contents ranged between 3 and 17 % (Table 3). Cumulative rainfall during the study was 89 mm. The maximum daily rainfall was 60 mm and occurred on the last day of the study (Fig. 1).

Significant increases in soil nitrate and ammonium contents (Fig. 3), were observed during the study, indicating bacterial activity and mineralization of organic matter. Maximum N_2O flux rate for the fertilized treatments was 297 µg N m^{-2} h^{-1}, and 196 µg N m^{-2} h^{-1} for the treatments that did not receive any fertilizer.

Over the 15-day period, total N_2O fluxes ranged between 12 and 31 mg N m^{-2} (0.1–0.3 kg N ha^{-1}) (Table 4).

Fertilizer-derived N_2O fluxes, calculated as the difference between fertilized treatments and treatments that did not receive fertilizer, were approximately 1% of fertilizer N applied. Although a trend of higher fluxes from treatments with higher N

TABLE 2
Some properties of incorporated organic residue

	Pueraria phaseoloides	Natural fallow
Biomass (Mg ha^{-1})	6.0 (1.5)	2.8 (0.4)
N added (kg ha^{-1})	148 (39)	47 (3)
Lignin (%)	9.8 (1.1)	8.6 (3.2)
Polyphenol (%)	1.2 (1)	1.2 (0.4)

Numbers in brackets indicate standard errors of the mean.

TABLE 3
Soil temperature, air temperature, and soil moisture content at sampling.

Sampling day	Air temperature (°C) Range	Soil temperature (°C) Range	Soil H_2O content (%) Range	Soil H_2O content (%) Mean
1	28–33	27–31	3–10	6.2 (1.0)
3	28–33	27–31	7–17	9.3 (1.6)
5	27–31	27–30	3–17	6.2 (2.3)
8	27–29	28–29	4–10	6.5 (1.0)
15	27–32	27–29	7–8	7.6 (0.1)

Numbers in brackets indicate standard errors of the mean.

TABLE 4
Total N_2O fluxes and fertilizer-derived N_2O fluxes after 15 days.

	Pueraria phaseoloides		Natural fallow	
	Range	Mean	Range	Mean
Total fluxes (mg N m^{-2})				
0 kg urea ha^{-1}	4.8–41.2	21.1(10.7)	5.4–15.5	11.8 (5.5)
15 kg urea-N ha^{-1}	17.2–47.2	30.5(8.9)	11.8–21.3	15.4 (3.0)
Fertilizer-derived fluxes				
mg N m^{-2}	0–22.1	9.2 (6.6)	0–7.6	3.6 (3.1)
%	0–1.5	0.6 (0.4)	0 –0.5	0.2 (0.2)

Total fluxes are calculated as the sum of the flux rates multiplied by time between sampling. Fertilizer-derived N_2O fluxes are calculated as (total fluxes from the 15 kg urea ha $^{-1}$-treatment) – (total fluxes from the 0 kg urea ha^{-1}-treatments). Numbers in brackets indicate standard errors of the mean.

input could be discerned, no significant differences could be distinguished among emissions from incorporated *P. phaseoloides* and natural fallow OR or levels of fertilizer application.

Discussion

Fluxes

Mean N_2O flux rates were 62 µg N m^{-2} h^{-1} for *Pueraria* and 35 µg N m^{-2} h^{-1} for natural fallow, in the treatments where no fertilizer was applied, and 82 µg N m^{-2} h^{-1} for *Pueraria* and 59 µg N m^{-2} h^{-1} for natural fallow in the treatments where 15 kg ha^{-1} of urea-N was applied. Flux rates in forest-based systems have been found to range from 1 to 31 µg N m^{-2} h^{-1} (Erickson and Keller, 1997; Weitz *et al.*, 2001, Palm *et al.*, 2002). It would appear that the flux rates observed in this study are greater than those from forest-based systems. This is consistent with the findings of Palm (2002) who reported greater flux rates in high- and low-input cropping systems compared to forest-based systems.

Dick *et al.*, (2001) reported peak flux rates of up to 2000 µg N m^{-2} h^{-1} after heavy rainfall in a Ugandan soil, which was correlated with

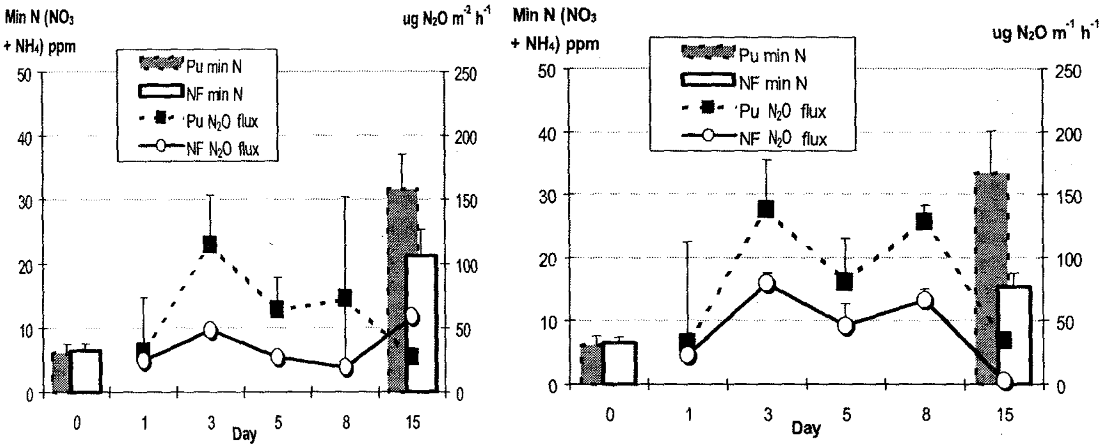

Figure 3a and b. N_2O flux rates and mineral N contents. Figure 3 shows flux rates and mineral N contents from the treatments that did not receive fertilizer, and figure 3b shows flux rates and mineral N contents from treatments where 15 kg ha^{-1} urea-N was applied. Error bars indicate standard errors of the mean.

high soil moisture contents. The results in this study do not indicate any significant correlation between soil moisture content and N_2O flux rates (data not shown), yet the erratic nature of rainfall and soil moisture conditions in the tropics could be an important factor.

Soil mineral N contents were significantly greater on day 15 than day 0 (Fig. 3), indicating mineralization and decomposition of the organic N. Yet, despite a seemingly increased mineral N content on day 15, flux rates were lower than on previous sampling occasions. However, assessment of the effect of mineral N availability and soil moisture contents on flux rates was not possible as (1) soil mineral N contents were not obtained on the other sampling days, and (2) sampling did not coincide with great variations in rainfall or soil moisture contents (Fig. 2, Table 4). These aspects remain to be investigated further.

Legume OM and fertilizer application

In a review of N_2O fluxes and the role of OM management, Baggs (2002) cited several studies where the incorporation of legume OM resulted in higher fluxes than after the incorporation of natural fallow OM, and these fluxes were related to differences in OM quality parameters (%N, lignin, polyphenol) and hence decomposability. In our study, *P. phaseoloides* and natural fallow had similar lignin and polyphenol contents, but there were clear differences in the N content (2.5% N for *P. phaseoloides* and 1.6% N for natural fallow) and the quantity of biomass (Table 2). This could explain the lower fluxes from the treatments where natural fallow was incorporated. Although the results for fertiliser derived N_2O fluxes (> 1%) were similar to other studies where fertiliser-derived N_2O fluxes typically ranged between 0,3-1,5% (Weitz *et al.*, 2001, Baggs *et al.*, 2002), the relatively short time period (15 days) should be noted, as these fluxes might be much larger if monitored over a more extended period.

The use of both inorganic and organic sources of N in the tropical cropping systems is thought to have positive effects on crop yields and soil fertility. Both positive and negative interactive effects of inorganic and organic amendments on N_2O fluxes have been observed in such systems, depending on OM quality and tillage (Baggs, 2002). Baggs (2002) reported a positive interaction when fertilizer was applied to legume mulch whereas a negative interaction, with reduced N_2O fluxes, was observed when fertilizer was applied to incorporated legume OM. The results from this study are in agreement.

In conclusion, initial N_2O fluxes from systems where *P. phaseoloides* OR is incorporated do not appear to differ from traditional systems where natural fallow is used. The combined use of fertilizer and OM in systems where OM is incorporated appears to have an interactive, relatively reductive effect on N_2O fluxes. Further studies, over a longer period, are needed for a better understanding of the factors that determine N_2O fluxes, and the management systems that reduce fluxes and increase agricultural productivity.

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