TRANSFORMATION IN SOIL AND AVAILABILITY TO PLANTS OF ^{15}N APPLIED AS INORGANIC FERTILIZER AND GRASS RESIDUE

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ABSTRACT
A pot experiment was conducted in the glasshouse at the Imperial College at Wye to study the transformations that occur following application of both inorganic and organic nitrogen (N) leading to availability to maize and losses into the environment. Organic N was applied as winter rye residue at the rate of 20 g per pot, whilst inorganic N was applied as double-labeled $^{15}NH_4{}^{15}NO_3$ (5 atom %) at the rate of 100 and 200 kg ha^{-1}. Watering was done when the soil began to dry up. Results indicate that N uptake by maize was affected by the rate and source of N application. Seventy-nine days after fertilizer application, 33 % of the N applied at 100 kg ha^{-1} was recovered in maize, but this was reduced to 24 % when the N application rate was doubled. Of the total N applied in the enriched rye residue, maize N recovery was 20.9 %, soil recovery was 53.2 %, and 0.002 % was lost through N_2O emission. By difference, the amount unaccounted for, 25.89 %, was presumably either leached out of the pots and/or incorporated into the soil microbial biomass.

Keywords: *Nitrous oxide, emission, nitrogen recovery, enriched, environment.*

INTRODUCTION

Nitrogen for agricultural crops productivity is applied in either organic or inorganic form. Before the N can be useful to crops, the applied N goes through a series of transformations which result in some of the N being lost as gases, some leached out, others incorporated into the soil organic system, and the rest absorbed by plants. There is always the potential for fertilizer N loss following application and incorporation of crop residue into the soil. Although the extent of N loss depends on the type and rate of application and the field conditions (Egginton and Smith, 1986; MacKenzie *et al.*, 1998), several workers have observed that about 30-50 % of fertilizer N applied is not taken up by crop plants, and becomes prone to loss into the environment (Chalmers and Darby, 1992; Peoples *et al.*, 1995). A number of workers have estimated the amount of N made available for crop uptake following application of organic residues. In a laboratory study, Handayanto *et al.* (1995) observed that up to 70 % of the N from legume pruning was recovered within 3 to 4 months. But in a field study N recovery from added residues by the first subsequent crop was reported to be 10 to 30 % (Giller and Cadisch, 1995). Other workers (Haggar *et al.*, 1993; Vanlauwe *et al.*, 1996) have reported that crop N recovery from organic inputs such as plant residues or manures is often less than 20 %. In a recent study, Hood *et al.* (2000) reported recovery between 22 to 61 % depending on the residue type method of determination and soil type. However, only a few (Azam *et al.*, 1985) have determined N recovery of fertilizer N and crop residues.

In the studies cited above, no mention was made about soil N recovery, neither was the amount of nitrous oxide (N_2O) lost reported. Additionally, most of these studies involved tree residues; no information was found on recovery from residues of small grain cereals like winter rye. In accordance with this, this study was carried out using a double-labeled $^{15}NH_4{}^{15}NO_3$ fertilizer (5 atom %) and isotopically labeled winter rye residues to determine estimates of crop and soil N recoveries as well as to determine the amount of N_2O emission.

MATERIALS AND METHODS

The experiment was undertaken in the glasshouse at Imperial College at Wye between March and October 2000. Twenty-litre pots (internal diameter 35 cm; basal diameter 30 cm; height 27 cm) were filled with 20 kg of soil (Coombe series). The pots had holes at the bottom to aid drainage. The initial mineral composition of the soil was determined prior to sowing. Maize (cv Soltis) was sown on 3 March 2000 at the rate of 4 seeds per pot at a depth of 3 cm and thinned to one stand 10 days after germination. Watering was done when the soil began to dry up. Double labeled $^{15}NH_4{}^{15}NO_3$ fertilizer (5 atom %) was applied on 22 March at the rates of 100 and 200 kg ha^{-1}. Because of the size of the experiment only 4 randomly selected replications received the enriched fertilizer whilst the other 12 replicates received the corresponding unenriched fertilizer at the same rates. Winter rye residue (enriched and unenriched) was incorporated at a rate of 20 g per pot in the treatments concerned on the same day. N concentration in the enriched residue was 2.6 % whilst that in the unenriched residue was 1.78 %. A randomized complete block design was established with 7 treatments, which were:

- 0 kg N without maize, (0N-M),
- 0 kg N with maize, (0N+M),
- ^{15}N enriched winter rye residue with maize, (OrN),
- 100 kg $^{15}NH_4{}^{15}NO_3$ ha^{-1} with maize, (100N),
- 100 kg $^{15}NH_4{}^{15}NO_3$ ha^{-1} with unlabelled winter rye residue with maize, (100M),
- 100 kg $^{15}NH_4{}^{15}NO_3$ ha^{-1} with unlabelled winter rye residue without maize, (100-M), and
- 200 kg $^{15}NH_4{}^{15}NO_3$ ha^{-1} with maize, (200N).

Plants were watered twice a week during the period of N_2O gas sampling, and thereafter when necessary.

Sampling

Gas samples were obtained from 4 randomly selected replications among those that had received the unlabelled fertilizer. The closed flux chamber technique (Smith *et al.*, 1995) was used and gas samples were analyzed for N_2O in a GCV chromatograph fitted with an electron-capture device. Soil was sampled once a week for a period of 6 weeks following treatment application from 4 randomly selected replicates where unlabelled fertilizer was applied to determine available NH_4^+ and NO_3^-. On each sampling occasion, 20-30 g of soil were taken from each plot and the KCl-extraction method (MAFF, 1986) was used to determine the concentrations of available soil NH_4^+ and NO_3^-. Maize plants were sampled three times on 27 April (SD1), 12 May (SD2) and 26 May (SD3) to determine treatment effects on maize leaf area, stem dry weight, leaf dry weight, leaf area, stem diameter and total plant dry matter yield.

Final harvest was done on 9 June (SD4). On each harvesting occasion, plants from 4 randomly selected replications, which were not being monitored for gas or soil data, were harvested separately. Plants were cut at 2 cm above the soil surface with a cutlass. After measuring the plant height and stem diameter, plants were divided into stems, leaves and cobs (when available), oven-dried at 80° C to constant weight, and their weights were recorded.

Maize plant samples were ground to <1 mm with a laboratory plant mill and total N concentrations in stem, leaves and cobs were determined by the micro-Kjedahl method. Dried maize plant residues from SD4 (from the replications that received the labeled fertilizer) were bulked together and ground as above. Soil samples from the above replicates were taken at the day of maize harvesting, oven-dried at 80° C and ground as above in a laboratory soil mill. Total N and atom % enrichment of N in the plant and soil were determined by mass spectrometry, and total N recoveries in plant and soil were calculated from the following equation:

%N recovery= [(R_{maize}*Total maize N)/($R_{residue\ or\ fertilizer}$*residue or fertilizer N added)] *100 where R= atom % 15N excess.

RESULTS AND DISCUSSION

N_2O emissions

Total N_2O emissions over the 28-day sampling period are presented in Fig 1. Emissions from the Control and the crop residue (OrN) treatments were not significantly different, but were each significantly ($p<0.05$) lower than emissions from the 100N treatment. Total emissions from the 200N treatment were significantly higher than from the 100N treatment. Total emissions higher from the 100-M treatment were significantly than ($p<0.05$) from the 100N and 200N treatments.

Total plant N %

Maize total N content was significantly affected by N application on all sampling occasions

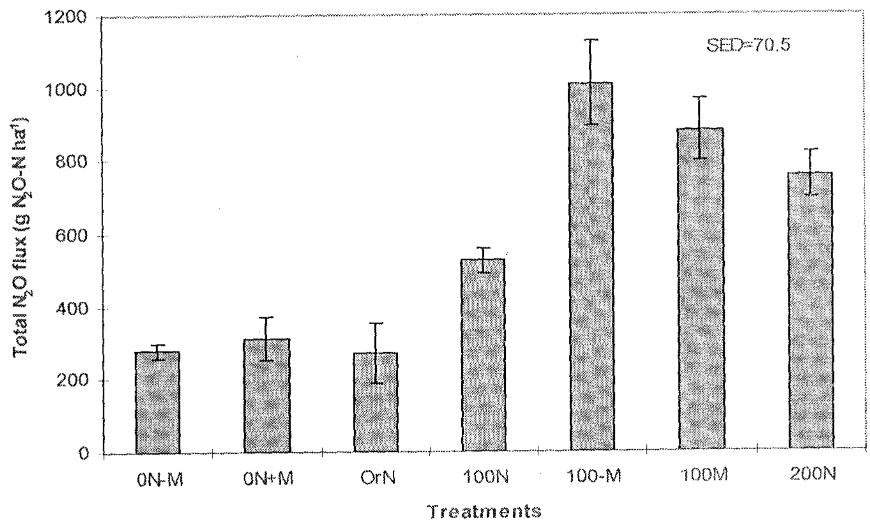

Fig. 1: Total N_2O emissions over 28-day sampling following N application rates of 0 (0N), 100 (100N), 200 (200N) kg N ha^{-1} and organic N (OrN) and residue incorporation in the glasshouse in 2000. The – M treatments did not have maize growing in them.

Table 1: Effect of N application and residue incorporation on maize total plant N % harvested at 4 sampling days

Treatment	SD1 (27 April)	SD2 (12 May)	SD3 (26 May)	SD4 (9 June)
0N+M	2.18	2.02	1.86	1.71
OrN	2.71	2.45	2.32	2.04
100N	3.35	3.10	2.72	2.24
100M	3.56	3.43	3.33	2.48
200N	3.49	3.25	2.95	2.52
LSD (0.05)	**0.41**	**0.37**	**0.40**	**0.34**

(Table 1). At SD1 and SD2, total plant N contents in the 100N, 100M and the 200N treatments were not significantly different. On both occasions, total plant N content in the OrN treatment was significantly higher ($p<0.05$) than in the 0N+M treatment. At SD3, total plant N content in the 100M treatment was significantly higher than in the 100N, OrN and the 0N+M treatments. Plant N content in the 100N and OrN treatments was significantly higher than in the 0N+M treatment. At SD4, total plant N content in the 100M and 200N treatments were significantly ($p<0.05$) higher than in the OrN and 0N+M treatments.

N recovery

Maize N recovery was significantly affected by the rate of N application (Table 2). Percent recovery in the 200N treatment was significantly ($p<0.05$) lower than in the 100N and 100M treatments. Incorporation of rye residue in the 100M treatment reduced recovery as compared to recovery in the 100N treatment, but the difference was not significant. Maize N recovery in the OrN treatment (rye residue alone) was significantly lower than in both the 100N and 100M treatments. On the other hand, soil N recovery was higher following incorporation of residues than where there was no residue. The highest

Table 2: N recovery (%) at harvest following application of rye residue and fertilizer N in the glasshouse

Treatment	Plant recovery (%)	Soil recovery (%)	Total recovery (%)
OrN	20.9	53.2	74.1
100N	33.3	43.2	76.5
100M	32.3	47.0	79.3
100-M	0	77.5	77.5
200N	24.1	22.4	46.5
LSD (0.05)	**5.6**	**10.3**	**8.4**

recovery was measured in the 100-M treatment (100 kg N ha^{-1}, without maize) whilst the lowest was measured in the 200N treatment. Recovery in the 200N treatment was significantly lower ($p<0.05$) than in all other treatments. Total N recoveries in the OrN, 100N, 100M and 100-M treatments were not significantly different, but were significantly higher ($p<0.05$) than in the 200N treatment.

Application and rate of N fertilizer significantly affected N_2O emissions. Total N_2O emissions following application of 100 and 200 kg N ha^{-1} were nearly 200 and 300%, respectively higher than emissions from the control treatment without maize (0N-M). Between the inorganic N treatments the total emissions from the 200N treatment was significantly higher than from the 100N treatment. Several workers including Cai (1997), Ledgard *et al.* (1999) have reported the enhancement of N_2O emission following fertilizer N application. The most appropriate reason given is that application of N fertilizer makes ammonium and nitrate ions available, which are substrates for the emission of N_2O (Ryden, 1981).

Residue incorporation and N application affected N recovery in maize. N recovered from the application of rye residue alone (OrN) was 20.9%, which was significantly lower than recovery in all other treatments, except in the 200N treatment. N recoveries in the 100N (100 kg N ha^{-1}) and 100M (100 N kg ha^{-1}, plus unenriched rye residue) treatments were not significantly different. Between the treatments that received 100 kg N ha^{-1}, soil N recovery in the presence of the residue was significantly higher than in the absence of residue. Soil N recoveries in these treatments were in the decreasing order 100-M>100M>100N. The difference between 100M and 100-M treatments may be due to the amount of N (32%) absorbed by the maize plants in the 100M treatment. Soil recoveries from the residue incorporated treatments were higher than those observed by Xu *et al.* (1993) who reported 35.5% soil N recovery following incorporation of *Leucaena* residues, whilst the test crop maize recovered 50.2%. Others have reported 46% (Harris and Hesterman, 1990) and 89% (Azam *et al.*, 1985) soil recoveries.

The 20.9% maize recovery from the enriched residue is similar to recoveries reported by other workers. Harris and Westerman (1990) found that maize recovered 17-25 % of total applied as enriched alfalfa residues. Ladd and Amato (1986) had earlier reported that between 11 and 28 % of N applied as medic (*Medicago litralis* L.) residues was recovered in the subsequent wheat crop. Cadisch *et al.* (1998) observed N recoveries of 9 and 44 % from *Calliandra* and *Glyricidia* pruning, respectively. Working with both fertilizer and crop residue, Azam *et al.* (1985) found that plants used only 20 % of the fertilizer, but this was reduced in the presence of the residues. In this study, maize plants used 33 % of the N applied at the rate of 100 kg ha^{-1}, and this was reduced to 24 % when the rate was doubled. Additionally the presence of the crop residue in the 100M treatment reduced the maize N recovery by 1 % as compared to that in the 100N treatment.

CONCLUSION

The results indicate that N uptake by maize was affected by the rate of N application. Seventy-nine days after fertilizer application, 33 % of the applied N at 100 kg ha^{-1} was recovered in maize, but this was reduced to 24 % when the N application rate was doubled. Of the total N applied, as enriched rye residue, maize N recovery was 20.9 %, soil recovery was 53.2 %, and 0.002 % was lost as N_2O emission. By difference, the amount unaccounted for, 25.89 %, was presumably either leached out of the pots or incorporated into the soil microbial biomass.

ACKNOWLEDGEMENT

The principal author was a British Academic Staff scholar and therefore financial assistance from British Commonwealth is greatly acknowledged. The technical support from Mr. Jon Fear, Wye College is deeply appreciated.

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