HOW ARE SOIL NITROGEN DYNAMICS IN IRRIGATED MAIZE SYSTEMS IMPACTED ON BY NITROGEN AND STUBBLE MANAGEMENT?

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Abstract

The soil nitrogen (N) dynamics of an irrigated maize system in which stubble retention and stubble burning treatments were superimposed over treatments of varying N fertilizer rate were studied. The field site is near Whitton, NSW, and the work described here is part a life cycle analysis of greenhouse gas emissions from maize project. The objective of this part of the work was to quantify the fate of fertiliser N applied at the site. Field measurements of denitrification, mineral N content and recovery of N-15 labelled urea from micro-plots with and without ATS (ammonium thiosulphate - a urease and nitrification inhibitor), were complimented with laboratory studies of denitrification and nitrous oxide (N_2O) flux.

Significantly more fertiliser N was recovered in the grain from the stubble incorporated treatment than the stubble burned treatment. There was greater recovery of fertiliser N in the soil at the end of the experiment in the stubble burned treatment. This may indicate that fertiliser N applied to the stubble burned system may be more exposed to soil-N transformations. The reason for the difference in uptake and soil residual is not clear, but may be related to soil structure differences leading to less plant accessibility of N in the burned treatment. This difference may lead to more N_2O emission from soil in the stubble burned treatments. Inclusion of ATS in the fertiliser formulation did not appear to have a significant impact on fertiliser N recovery.

Introduction

Nitrous oxide (N_2O) is primarily produced in soil by the microbial process of denitrification, although nitrification also contributes some N_2O emission. Denitrification is an anaerobic process which occurs when the soil is wet, and involves the use of nitrate (NO_3^-) by bacteria as an alternative electron acceptor to oxygen during respiration. Denitrification converts NO_3^- to N_2O, which may then be further reduced to nitrogen (N_2). Nitrification on the other hand is an aerobic process, whereby ammonium (NH_4^+) is oxidized to NO_3^-. The production of N_2O through nitrification and denitrification relies on the presence of substrate and conditions amenable to significant reaction rates. The substrate for these reactions, NH_4^+ and NO_3^- for nitrification and denitrification respectively, are subject to other reactions such as absorption by plants and loss by leaching and runoff (in the case of NO_3^-). Nitrous oxide formed may also be subject to further transformation, in particular through further reduction to N_2. In order to contextualize emissions of N_2O from an irrigated maize system, it is necessary to quantify the interacting N processes in the soil-plant system either competing or supplying substrates for N_2O producing processes.

Transformations of N are strongly influenced by the water content of soil, controlling the availability of both water and oxygen. Soil structure is a primary controller of ease of movement of gases, water and plant roots, and of the soil's capacity to store water. In turn, soil structure may be sensitive to agronomic practices such as stubble management.

Transformations of N may also be impacted on through the use of chemicals that inhibit the activity of enzymes that mediate particular processes. Ammonium thiosulfate (ATS) has been found in laboratory studies to inhibit both urea hydrolysis and nitrification (Goos 1985). There is considerable interest in the use of this chemical in conjunction with urea, in order to provide a supply of NH_4^+ to plants such that there is little NH_3 volatilization and less NO_3^- produced which could be leached or denitrified.

The study described in this paper addresses the following questions in relation to N_2O emissions from irrigated maize systems:

Does stubble treatment influence the fate of fertiliser N?
Does ATS influence the fate of fertiliser N?
Are N_2O emissions sensitive to N fertiliser rate?

Materials and methods

The site at Whitton is described in Beer et al. (2006) and Kirkby et al. (2006) (these proceedings), as are the major agronomic activities that took place there. Field and laboratory activities were undertaken quantify N transformation processes occurring at the site. Denitrification was estimated using acetylene inhibition methods in the field and laboratory. It was only possible to apply the field incubation method approximately 2 days after irrigation due to difficulty accessing the plots. This necessitated use of laboratory incubation methods to estimate denitrification during the wetting up and early drying stages.

1. Laboratory incubation studies

Incubations were conducted in the laboratory in 1 L gas-tight vessels in which head space could be sampled and refreshed. The objectives of these incubations were to quantify the interacting effects of soil mineral-N concentration, soil water content [expressed as water filled pore space (WFPS)], temperature, and available C on the rate of nitrification, denitrification and N_2O flux.

2. Field studies

(a) In situ denitrification

To measure the rate of denitrification, the key process contributing to N_2O emission. The rate of denitrification was measured *in-situ* on three treatments (0N-burned, 300 kg N/ha/y stubble burned, and 300 kg N/ha/y stubble incorporated) using the acetylene inhibition intact core technique. Cores were placed into gas-tight jars and acetylene was injected to block the conversion of N_2O to N_2 (Mahmood et al. 1999, 2005). A set of cores incubated similarly but without the acetylene to account for N_2O in the headspace that was not from denitrification. Measurement of N_2O in the headspace can then be used to calculate the amount of N lost through denitrification as N_2O or N_2.

(b) ^{15}N mass balance

To measure the amount of fertiliser N that was taken up by plants, remained in the soil, or was lost to the atmosphere or lost by leaching and runoff, the fate of ^{15}N in ^{15}N-labelled urea was followed. The equivalent of 200 kg N/ha as ^{15}N-enriched urea was applied to stainless steel microplots (50 x 60 cm) in the 300 kg N/ha stubble burned and 300 kg N/ha stubble incorporated treatments, 6 December 2004, at the time when the second application of fertiliser was being applied to the rest of the field (13.04 g of urea (6.0 g of N) per microplot). The treatments in the microplots were i) stubble incorporated beds, 200 kg N/ha as ^{15}N-enriched urea, plus 5% ATS, ii) stubble incorporated beds, 200 kg N/ha as ^{15}N-enriched urea without ATS and iii) stubble burned beds, 200 kg N/ha as ^{15}N-enriched urea plus 5% ATS. The microplots were installed from the centre of bed to just over the bed shoulder and pushed in to 25-30 cm. Each microplot contained three maize plants. There were 4 replicates per treatment (total 12). The equivalent of 100 kg N/ha of unlabelled urea had been applied two weeks earlier. The soil and plants from the microplots were collected approximately 2 weeks prior to field harvest (between physiological maturity and mechanical harvest), and analysed for N content and N isotope ratio.

(c) Measurement of N_2O fluxes with small static chambers

Short-term (1 hour) field measurement of N_2O with static minichambers (Turner et al. 2005) were carried out to evaluate the sensitivity of N_2O emissions to fertiliser rate and stubble treatment. 18 minichambers were used for each stubble x rate treatment (three lines of 6 minichambers from furrow centre to bed centre). Soil samples (0-10 cm) were collected under each static chamber for one set (18-23 December 2004).

Results and discussion

Laboratory incubations

Nitrification

Nitrification is the process in which NH_4^+ is oxidized by chemoautotrophic bacteria to NO_3^-. Some N_2O is formed as a by product of this reaction. Generally the contribution of nitrification to the total yield of N_2O from irrigated and fertilized soil is small compared to that produced through denitrification. Nitrification is however, the process through which NO_3^- is formed, which is then the substrate for denitrification reactions. A series of incubation experiments were conducted to test the nitrifying power of the soil, and to test the sensitivity of nitrification to environmental variables expected at the site. The maximum reaction rate measured indicates that about 15 kg N/ha/day could be nitrified.

Temperature impact on nitrification

Nitrification rates at 10°C and 20°C were similar, and started to decline above 30°C. Based on the experimental results, it appears that this soil has a wide optimal temperature range (11-27°C) for nitrification, and that the reaction rate is unlikely to be impeded by unfavorable temperatures at the site during the maize season

Water filled porespace (WFPS) impact on nitrification

The optimal WFPS (the percentage of the total porosity filled with water) for nitrification process in this soil is 50%. Above about 60% WFPS the rate of nitrification diminishes due to lowering of the diffusivity of O_2 to the bacterial cells.

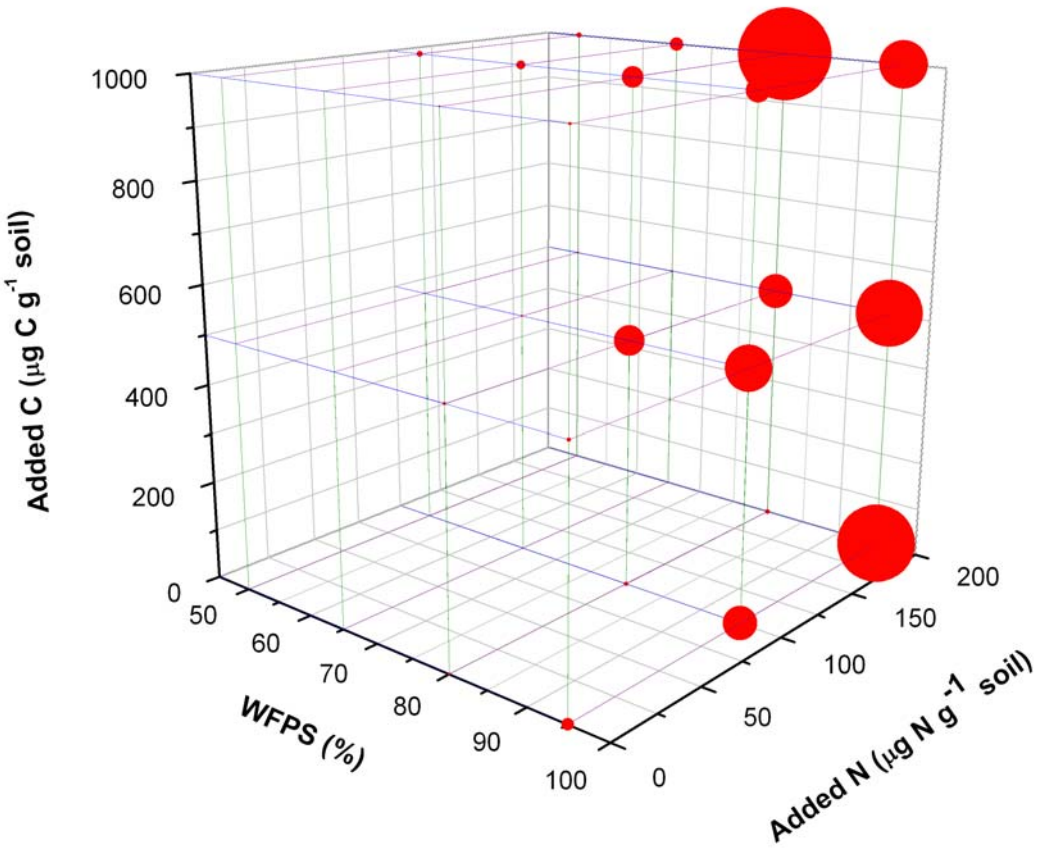
Denitrification

N_2O emissions affected by WFPS (%), added N and C.

Soil samples were collected from the 300 kg N/ha stubble incorporated plots to quantify the effect of varying WFPS, dissolved C and N on N_2O emission. Soil was taken from 0-10 cm prior to fertiliser application. After preincubation for 7 days just below the target moisture content, treatments of C, N and WFPS were imposed and the emission of N_2O measured for 10 days.

Emission of N_2O was most sensitive to added N and WFPS, and insensitive to addition of C (Figure 1). The size of the circles indicates the magnitude of the N_2O emission. The insensitivity to C indicates that the system was non-limiting in regard to C. This is particularly applicable to WFPS treatments above about 70% where denitrification dominates N_2O emission, as denitrification requires organic C and nitrification does not. The emission from all but the highest added N treatment was largest from the highest WFPS treatment (WFPS = 95%). This indicates that denitrification is the dominant process producing N_2O.

Figure 1. Response of N_2O emission rate to WFPS and additions of C and N. The area of the circles reflects the size of the emission rate.



Denitrification incubation with fresh soils

To quantify the amount of denitrification resulting from the first application of fertiliser at the time of sowing, samples were collected and incubated under optimal condition for N_2O emission (90% WFPS at 30°C). There was no significant difference in denitrification rate between the two stubble treatments, however there was a clear rate dependence (Figure 2). A denitrification rate of 1000 ng/g/day is approximately 1 kg N/ha/day from the top 10 cm of soil (with soil dry bulk density of 1 t/m^3). At this stage the difference between the fertiliser rate treatment plots was not due to the application of fertiliser at the time of sampling, as all the fertilised plots had received the same initial dose (100 kg N/ha). Rather differences observed were the result of previous fertiliser history.

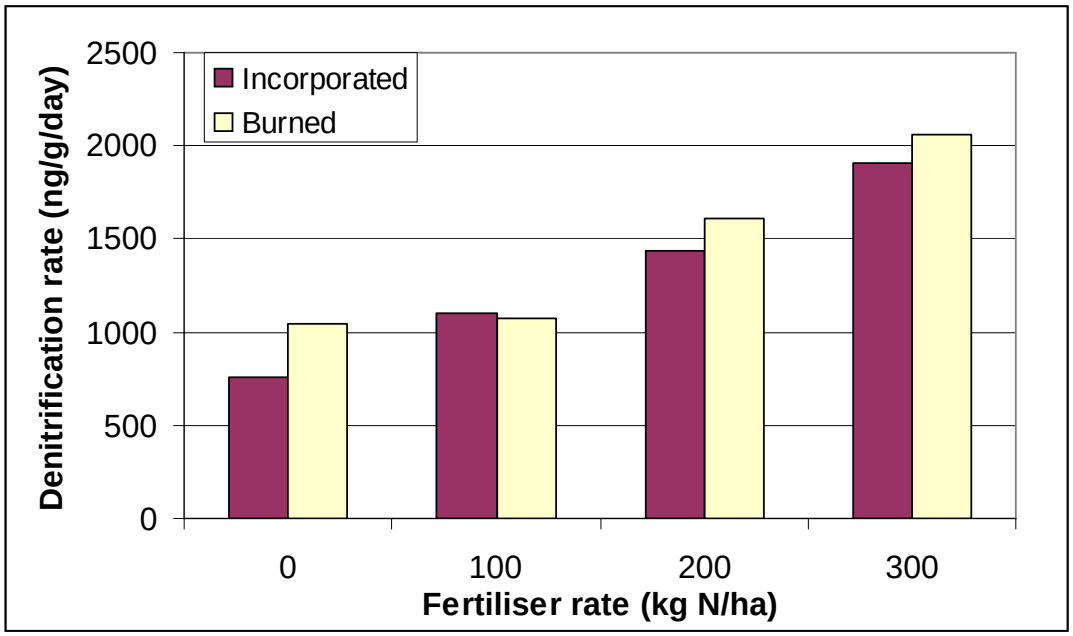
Field studies

In-situ denitrification

Denitrification was measured in the field using the acetylene inhibition intact core method on 2 occasions, Dec 7-10 2004 (for 3 days) and Dec 20-21 2004 (for 2 days). Measurements commenced 2 days after irrigation, and therefore are likely to have missed peak emissions. The loss rate of N through denitrification during the periods between irrigation events estimated by this method was 20 to 66 g N/ha/day. There was ample NO_3^- present in the soil in the 1N treatments: averages (+/- standard errors) were 47 (5) and 60 (9) mg NO_3^--N/kg soil on Dec 10 and 21 2004 respectively.

As there was no clear time pattern in denitrification or substrate abundance in the fertilized plots, and assuming these rates were applicable to three months of irrigation season, the amount lost would be in the order of 2 to 6 kg N/ha. On the basis of soil N analyses, there appears to be non-limiting concentrations of NO_3^- for denitrification. In order to calculate an estimate of denitrification that includes the peaks of emission immediately after irrigation, it was assumed that denitrification proceeded at approximately 2.9 kg N/ha/day for 2 days after each of 6 irrigation events (on the basis of denitrification potential incubations). This leads to an estimate of total loss through denitrification of 39 kg N/ha, or 13% of applied N.

Figure 2 Average denitrification rate over 8 days in soils after first application of fertiliser.



It should be pointed out that the inherent limitations of this method may lead the underestimation of the denitrification rates. The two main limitations are (a) missing the peak denitrification fluxes due to inaccessible to the field immediately after the irrigation; (b) not achieving 100% inhibition of N_2O to N_2 because of uncertainty about C_2H_2 distribution in microsites inside soil aggregates, particularly for the heavy clay soil.

^{15}N mass balance

Substantial losses of applied fertiliser were observed from the ^{15}N microplots, with total recovery of fertiliser N of only 64-68% (Table 1) (no significant differences between treatments at $P<0.1$ for total recovery). There was no effect on the N recovery in any of the components due to the addition of ATS (in the stubble incorporated plots). There was however, significantly more fertiliser recovered in the soil of the burned treatment than in the soil of the incorporated treatment, and significantly less fertiliser recovered in the grain of the burned treatment than in the grain from the incorporated treatment ($P<0.05$). There was no significant difference in N concentration in the grain, and the higher recovery in grain in the incorporated plots reflects higher grain yields. Similarly higher yields were observed in the incorporated treatments outside the ^{15}N microplots. The percentage of N in the plant that apparently came from applied fertiliser was only 29% in the Burned treatment plots and 33% in the Incorporated plots, indicating the importance of soil N stores to the maize N-economy.

Nitrous oxide fluxes with small static chambers

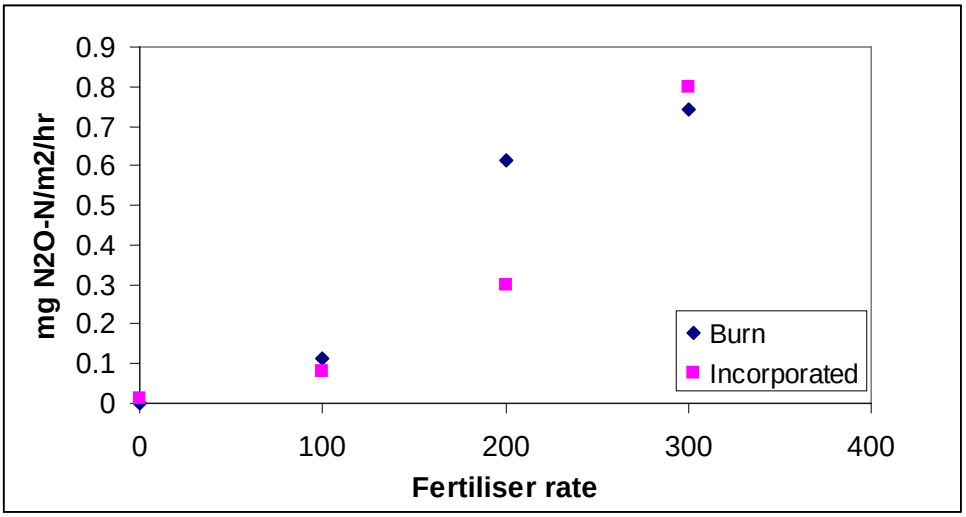
There was a strong fertiliser rate dependence for N_2O emissions measured in static chambers two weeks after fertiliser application (Figure 3). Increasing the rate of fertiliser N from 100 to 300 kg N/ha resulted in an approximate 8-fold increase in the N_2O emission rate.

No difference between stubble treatments was observed. The chambers (15 cm diameter, 3 L volume) were placed in 6 positions from the middle of the furrow to the middle of the bed.

Table 1. Recovery of labeled fertiliser in different sample types and treatments (4 microplots per treatment. All treatments received the equivalent of 100 kg N/ha of unlabelled fertiliser, and 200 kg N/ha as labeled fertiliser. Inc = Stubble Incorporated treatment; Burned = 1N Stubble burned treatment; ATS = ammonium thiosulphate).

	% recovery of N-15 Fertiliser. mean (se)		
Sample type	Burned +ATS	Inc +ATS	Inc -ATS
0-20 cm soil	30 (4)	21 (5)	19 (3)
20-60 cm soil	5.7 (1.1)	2.3 (0.4)	2.4 (0.3)
roots	1.8 (0.4)	2.3 (0.2)	2.1 (0.5)
stem	8.9 (0.6)	10 (1.1)	10 (0.2)
grain	22 (2)	29 (3.3)	29 (2.7)
total	68 (3)	65 (3)	64 (1)

Figure 3. N_20 emissions from static chambers, based on the average of 18 chambers covering furrow to bed centre positions.



Conclusions

Only 64-68% of applied labeled fertiliser was recovered from the N-15 microplots (Table 2). Given that the fertiliser was applied in solution and injected below the soil surface NH_3 volatilization is likely to be an insignificant pathway of N loss from this system. Soil analysis and laboratory incubations show that nitrification occurs rapidly in this soil. The limited snapshot field measurement of the denitrification using acetylene inhibition methods may under-estimate the denitrification soon after irrigation, and laboratory incubation data was needed to estimate peak denitrification. As a result, there is considerable uncertainty associated with the denitrification estimates. Since the losses of N by drainage and runoff were calculated by difference from the other pools, the uncertainty associated with this fate is similar to that for denitrification losses. Actual losses of N in runoff and drainage will be improved through modeling.

So:
Does stubble treatment influence the fate of fertiliser N?

Yes: Significantly more fertiliser N was recovered in the grain from the stubble incorporated treatment than the stubble burned treatment. There was greater recovery of fertiliser N in the soil at the end of the experiment in the stubble burned treatment.

This may indicate that fertiliser N applied to the stubble burned system may be more exposed to soil-N transformations. The reason for the difference in uptake and soil residual is not clear, but may be related to soil structure differences leading to less accessibility of N in the burned treatment. This difference may lead to more N_2O emission from soil in the stubble burned treatments.

Does ATS influence the fate of fertiliser N?

No: Inclusion of ATS at 1% in the fertiliser formulation did not appear to have an impact on N recovery of fertiliser applied at 300 kg N/ha.

Are N_2O emissions sensitive to N fertiliser rate?

Yes: Nitrous oxide emission rate was strongly dependent upon fertiliser rate and was responsive to rate throughout the range of fertiliser application tested (0-300 kg N/ha). There was no apparent effect of stubble management on N_2O emission rate two weeks after fertiliser application, however late in the season differences may develop as there was an observed difference in residual fertiliser N between stubble treatments.

Table 2. Estimated fate of fertiliser N (% applied) from N-15 microplots to the time of harvest

	Treatment			
Fate of fertiliser N	Burned +ATS	Inc -ATS	Inc +ATS	Confidence
to grain	22	29	29	4
to vegetative parts	11	12	12	2
remaining in soil	36	21	23	5
denitrified	13	13	13	5
leached or in runoff	19	25	23	5

Acknowledgements

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