Nitrogen fertiliser increases nitrous oxide emissions from a semi arid Vertosol

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Abstract
Nitrous oxide (N_2O) has 300 times more climate warming effect than carbon dioxide so the accurate measurement of N_2O emissions from agricultural soils is important for the verifiable accounting of greenhouse gas emissions. Studies of wheat production systems in semi arid regions of Australia have so far indicated low emissions of N_2O by international standards, however the studies are limited. We examined the emissions from a typical rainfed Vertosol growing winter wheat in south-eastern Australia. Continuous gaseous measurements using an automated enclosure chamber system were combined with the simultaneous monitoring of soil water, temperature, mineral nitrogen (N) and weather parameters. The agronomic treatments were winter wheat grown without N fertiliser, following either a grain legume crop (fieldpeas) or a legume pasture (medic), or wheat grown with N fertiliser following a crop of canola. In a relatively dry year, the N_2O emissions were similar in scale to other Australian studies from semiarid climates. The application of N fertiliser at sowing increased N_2O emissions for approximately two months. The use of previous legume crops to supply N for following wheat crops may reduce N_2O emissions from this cropping system.

Key Words
Greenhouse gas, wheat, N_2O, emissions factor, south eastern Australia.

Introduction
Australian agriculture was responsible for an estimated 16% of the net national greenhouse gas emissions in 2006, and contributed 84% of the nitrous oxide (N_2O) emissions, 75% of which resulted from the nitrogen (N) enrichment of agricultural soils (Department of Climate Change 2008). The sources of N enrichment include synthetic fertiliser. The Intergovernmental Panel on Climate Change (IPCC) has estimated that 1.25% of all N fertiliser applied to soil in the northern hemisphere is lost as N_2O. However, N_2O emissions from N fertiliser applied to Australian crops have been found to be much less (Barker-Reid *et al.* 2005), reflecting the drier nature of Australian agro-ecosystems and low N application rates by international standards. Although only a few comprehensive studies have been made of N_2O emissions from rained-fed crops in semi-arid climates (Barton *et al.* 2008), the fertiliser emissions factor for rain-fed cropping in Australia has been reduced to 0.3% (Department of Climate Change 2008). Our objectives in this study were to measure gaseous emissions and establish the fertiliser emissions factor of wheat in a typical south east Australian rainfed cropping environment on alkaline soils. Measurements of gaseous N_2O emissions were made 24 hours a day and combined with measurements of soil water, temperature, plant available N and weather parameters.

Methods
The study site was near Horsham, on the Plant Breeding Centre farm (36°45'S; 142°8'E), in the Wimmera region of Victoria. The Wimmera has a temperate climate with mediterranean style hot, dry summers, and cool to mild winters that are relatively wet (Cawood *et al.* 1996). The soil type was a Kalkee Clay, which is an alkaline expanding-clay Grey Vertosol (Martin *et al.* 1996; Isbell 2002). The trial was a randomised block design consisting of three treatments replicated three times. Winter wheat (*Triticum aestivum* cv. Carra) was grown in three treatments; (1) Rain-fed wheat with no nitrogen fertiliser following a crop of medic (*Medicago truncatula* Gaetn. cv. Mogul), (2) Rain-fed wheat with no nitrogen fertiliser following a crop of fieldpeas (*Pism sativum* cv. Kaspa), (3) Rain-fed wheat with 50 kg N/ha urea fertiliser side-banded at sowing, following a crop of canola (*Brassica napus* cv. Beacon). Gas collection commenced on 8 March 2008 and ended on 7 April 2009. The growing season was relatively dry (195 mm compared to the long-term average of 268 mm for June to Nov) and supplementary irrigation was applied on the 3rd (14 mm) and 15th - 16th (30 mm) of October. The cultivation (minimum tillage) and fertiliser rates were otherwise representative of farming practices in the region.

Measurements of N_2O were made using automated gas collection chambers. The collection chambers consisted of moveable boxes (0.8 m x 0.8 m x 0.5 m high) constructed from stainless steel and polycarbonate, which were clipped to an open stainless steel base unit (0.8 m x 0.8 m x 150 mm depth) that was pressed approximately 100 mm into the soil. Two base units (0.5 m apart) were installed in each plot so that the position of the chambers could be alternated weekly. As the crop grew an extension box of similar construction was fitted to each chamber to double its height. The nine automated gas collection chambers were located at one end of the agronomic plots (plot size 7 m x 15 m) and were programmed to measure N_2O flux in a closed chamber 16 times a day. The lids of the three chambers within a replicate group closed simultaneously for 30 minutes, and the air from each chamber of the group was then sampled sequentially for 30 seconds every three minutes. Gas samples were distributed through a pressure controlled manifold and driers, to a tuneable diode laser trace gas analyser (Campbell Scientific Inc.), which measured N_2O adsorption in continuous comparison to a standard concentration N_2O gas. During each cycle, instrument grade air was also sampled as a working standard gas to correct for offset errors, as well as the ambient air. Flux was determined by calculating the rate of change in N_2O concentration (corrected to density) from ten measurements over the 30 minute period (Barton *et al.* 2008). The chambers vented automatically during the closure time if the temperature in the chambers exceeded 50^oC, or if the site received 0.51 mm rain in 5 min.

Soils were characterised using standard methods (Rayment and Higginson 1992) prior to plot establishment in 2008 for bulk density, pH (1:5 $CaCl_2$), electrical conductivity (EC) in 1:5 w/v solution, exchangeable sodium percentage (ESP), total nitrogen (Leco FP2000, MI, USA) and plant available N (air dry soil<2mm, 2M KCl extraction). Permanent wilting point (PWP) and field capacity (FC) were determined by pressure plate method at -1500 and -30 kPa respectively (Klute 1986). Potentially mineralisable nitrate (AMN) was determined from samples collected in July 2008, as the difference in KCl extractable N between post-incubated and non-incubated extracts (Sparling and Searle 1993). Soil water content in the surface soil (0-60 mm depth) was monitored in each chamber base using thetaprobes (Theta-Probe MK2x, Delta-T Devices Ltd).

Results and discussion

Daily N_2O emissions ranged from -0.37 to 9.3 g N_2O-N/ha/day over the trial period for the three treatments. The mean daily emission was 0.45 g N_2O-N/ha/day, although the data set was highly skewed and so the median rate of emission was 0.11 g N_2O-N/ha/day. Prior to sowing, the autumn season of 2008 (March to May) was relatively dry and soil moisture in the top 50 mm was below PWP until the "break" rainfall event on the 16th of May (Table 1). The N_2O emissions were relatively small (Figure 1) throughout this period. The average rates of emission until sowing were 0.18±0.22 g N_2O-N/ha/day for medic stubble, 0.1±0.16 g N_2O-N/ha/dayfrom pea stubble, and 0.09±0.09 g N_2O-N/ha from the canola stubble treatment.

The wheat was sown in the plots on 6 June 2008. Seasonal conditions improved during winter, with 151 mm rain falling from June to August. The soil moisture reached field capacity in the topsoil on the 8th of July (Figure 1). Emissions from the fertilised plots increased in comparison to the other treatments, but only between 10 June and 16 August 2008. In this period, the wheat + N fertiliser treatment released 152 ± 31 g N_2O-N/ha/day, compared to 65±17 g N_2O-N/ha/day from wheat sown in medic stubble and 52 ±28 g N_2O-N/ha/day from wheat sown in pea stubble. When the entire June to December cropping period was considered, the soil under wheat + N had a significantly greater rate of emission compared to soil under wheat that was sown in pea stubble with no N fertiliser ($P<0.05$).

Table 1. Soil properties in a Vertosol in the Wimmera region of Victoria, under summer fallow in February 2008 following crops of either medic, field peas or canola, including soil bulk density (BD), permanent wilting point (PWP), field capacity (FC), electrical conductivity (EC), Exchangeable Sodium percentage (ESP) and plant available N (Mineral N).

Depth	BD	PWP	FC	pH	EC	ESP	Total N	Mineral N (µg N/g soil)		
m	g/cm^3	%v/v	%v/v	$CaCl_2$	1:05	%	%	Canola	Medic	Pea
0.0-0.1	1.12	23.1	41.2	7.9	0.25	3.9	0.08	16.5	36	27.2
0.1-0.2	1.23	26.8	46	8.1	0.25	5	0.04	7.7	14.2	12.6
0.2-0.4	1.26	26.7	45.7	8.2	0.36	6.5	0.03	9.5	9.8	12.2
0.4-0.6	1.32	31.3	52.7	8.4	0.5	8.9	0.02	5.7	12.3	7.4
0.6-0.8	1.34	33.4	59.5	8.6	0.74	11.7	0.01	7.2	5	6.3
0.8-1.0	1.39	36.3	62.6	8.6	1.08	13.8	0.01	5.7	4.6	4.2
1.0-1.2	1.37	35.9	64.1	8.7	0.99	15.2	0.01	6.9	5.7	5.2

The amount of background N in this soil is relatively low (Table 1) and a sodic subsoil restricts the root depth in these very alkaline soils (Hazelton and Murphy 2007) so that the available N can be manipulated by the crop rotation. The objective of the pre-treatments was to reduce plant available N in the canola plots, so that the amount of N would be similar across the treatments when the ex-canola plots were fertilised at sowing. We confirmed that soil mineral N (nitrate plus ammonium) in the summer fallow stage in February 2008 had been reduced in the canola stubble plots, compared to the plots in medic and pea stubble (Table 1). There was approximately 57 kg/ha more mineral N in the top 600 mm of the medic plots, and 38 kg/ha more mineral N in the pea stubble plots, compared to the soil under canola stubble. Subsequent analysis of the potentially mineralisable N (AMN) in July 2008 also found that there was less mineralisable N in the top 100 mm of the canola stubble plots (50±17 µgN/g soil compared to 67±15 µgN/g soil for ex medic and 60±22 µgN/g soil for ex peas). The medic stubble plots therefore contained an estimated 72 kg potentially mineralisable AMN-N/ha in the top 10 cm, while the pea stubble contained 66 kg AMN/ha, compared to 52 kg N/ha in the canola plots. The increased emissions from the fertilised plots therefore may have been caused by a difference in the form of N in the soil (nitrate, ammonium or organic) rather than a difference in the quantity of N.

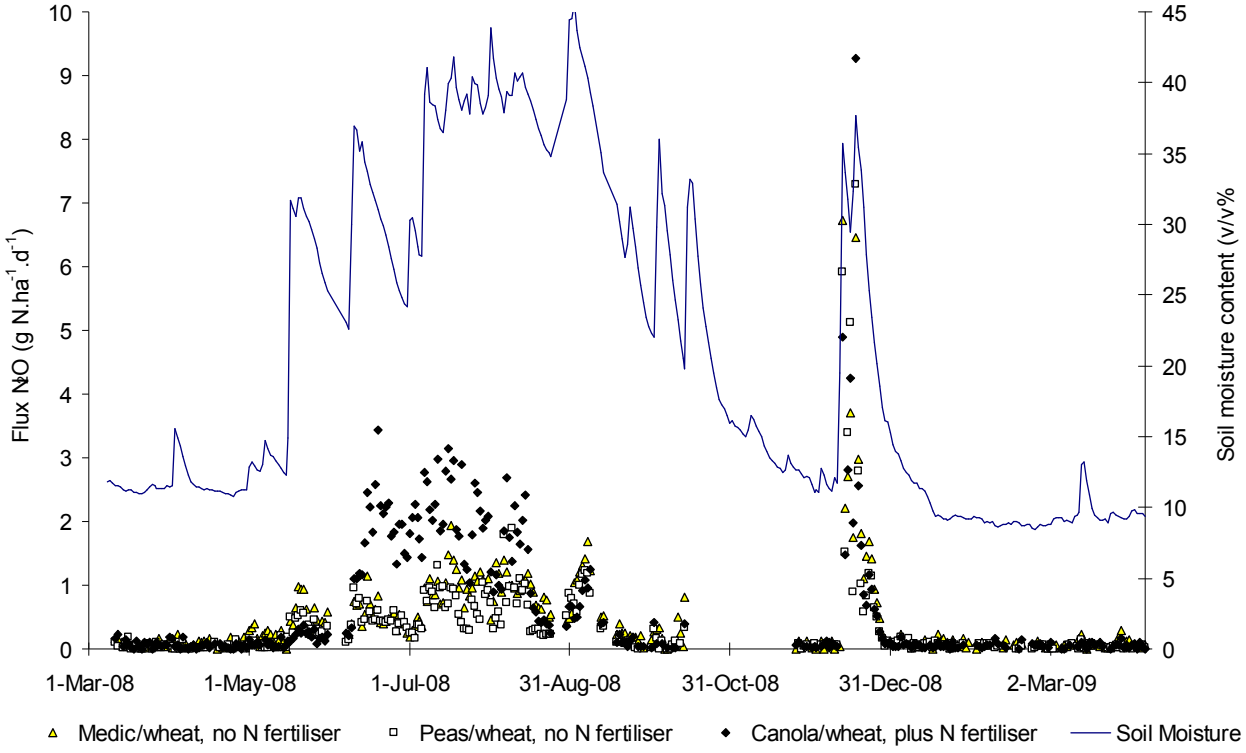

Figure 1. Soil emissions of nitrous oxide and changes in soil moisture, from wheat in the Wimmera region, Victoria.

The amount of winter rainfall was close to the long term mean but only 44 mm rain fell from September to November, which was a third of the long term expected rainfall for spring. Despite supplementary irrigation on 3rd, 15th and 16th of October, the soil moisture levels declined and had returned to PWP (crop lower limit) by late October. Equipment breakdowns between 15th October and 24th November caused an unfortunate gap in the data but only 11.4 mm of rain fell during this period, so the emissions are expected to have been minimal.

The initial wheat establishment was uneven and subsequent growth was poor, resulting in very low grain yields (mean 0.67 t/ha) and no significant differences between the agronomic treatments. Conditions after harvest remained very dry until 72 mm rain fell between the 9th and 17th December. There was a resulting peak in emissions for a short period (Figure 1), before rapidly declining as the soil moisture returned to PWP. Subsequently, only 15 mm rain fell, so conditions remained dry and emissions were minimal until the experiment was terminated in early April 2009.

The N_2O emissions from this study in 2008–09 were similar to those recorded from a wheat crop growing in a temperate climate on acid soils in Rutherglen, Victoria (Barker-Reid *et al.* 2005), and in a semi-arid climate on acid sandy soils in Cunderdin, Western Australia (Barton *et al.* 2008). A fertiliser emissions factor was calculated for the Wimmera site, based on the annual difference between the N_2O-N emitted by the fertilised soil under canola stubble and the average of the unfertilised treatments, divided by the amount of fertiliser applied (50 kg/ha N). The average fertiliser emissions factor for the whole monitoring period was 0.16%, confirming that a reduced emissions factor is appropriate for N fertiliser applied to semiarid rainfed grain crops in Australia.

Conclusions

The growing season rainfall (April to October) for 2008 was only decile 1 in the Wimmera (Price and Sounness 2008). In this year, the N_2O emissions from wheat cropping soils, and the fertiliser emissions factor, were both similar to two other studies made in Australian wheat crops. Despite the dry conditions in 2008, there was a clear flux response to the application of N fertiliser, which caused a threefold increase in N_2O emissions that lasted for 68 days. The use of legumes, instead of fertiliser, as a source of N for wheat crops may reduce N_2O emissions from cropping soils.

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