Nitrous oxide emissions from acidic Black Vertosol: effects of residues, nitrogen additions and pH

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Abstract

Agricultural soils are a major source of atmospheric nitrous oxide (N_2O), a potent greenhouse gas contributing approximately 6% of the total radiative forcing from anthropogenic greenhouse gas emissions. Vertosols are the major soil type throughout much of the grain-growing areas of northern NSW and southern Queensland in Australia. In these areas, cultivation of grain legumes, retention of crop residues after grain harvest and increased use of fertilizer-nitrogen (N) are common practices, all of which are potentially important sources of N_2O emissions. Vertosols are fine-textured and have poor internal drainage, which can lead to greater periods of saturated, anaerobic conditions conducive to N_2O emissions through denitrification. This underlines the need to better understand the relative contribution of different N sources (i.e. fertilizer-N, crop residue-N, biologically-fixed N_2) to N_2O emissions from cropped Vertosols in order to define the least emitting system. The long-term aim is reduction of N_2O emissions from Australian agricultural systems.

In the five experiments reported in this thesis, I examined the relative effects of fertilizer-N rates and biologically-fixed N_2 on N_2O emissions from an acidic Black Vertosol and further examined the effects of residue sources, particularly root *versus* shoot, and soil pH on N_2O emissions from the same soil. Previous studies indicated that a significant amount of N (30–50% of total plant N) remains below-ground after grain harvest. This constitutes a major portion of residue-N and C and could be an important factor affecting N_2O emissions during residue decomposition. The relevance and importance of below-ground residues was explored throughout the experiments, particularly in those examined in Experiments 2 (Chapter 4) and 3 (Chapter 5).

In the first two experiments, I attempted to mimic field conditions of plant growth and residue decomposition by growing both winter (Chapter 3) and summer (Chapter 4) crop plants in 75-cm long cylindrical cores, repacked with soil from a nearby field, in a glasshouse. Watering was facilitated by an overhead watering system to simulate natural rainfall. After grain harvest, all above-ground plant residues were returned to the soil surface. Below-ground residues remained *in-situ* in the soil. Nitrous oxide emissions from each pot

were measured weekly during the growing season and fortnightly during the post-harvest fallow using a manual chamber method.

In Experiment 1 (glasshouse study), crop species were wheat (*Triticum aestivum*) and canola (*Brassica napus*), and both were fertilized at low N (50 kg N ha^{-1}) and high N (150 kg N ha^{-1}) rates at sowing. Nitrous oxide fluxes ranged from −0.5 to 374 µg N_2O-N m^{-2} h^{-1} in the growing season and from 3.31 to 633 µg N_2O-N m^{-2} h^{-1}during the post-harvest period. Increasing the fertilizer-N rate increased cumulative emissions from wheat pots by 70% and from canola pots by 118% during the two-month period following fertilizer application. Two thirds of the annual N_2O emissions occurred during the post-crop fallow, which was related to soil moisture content and cumulative rainfall. On average, post-crop N_2O emissions from wheat pots (LN and HN) tended to be higher than for canola, which was presumably in part due to the higher soil moisture contents of the former resulting from earlier maturity, and possibly also to earlier residue decomposition.

The main objective of Experiment 2 (glasshouse study) was to compare the magnitude of N_2O emissions during plant growth and *in-situ* residue decomposition of soybean (*Glycine max* L.), grown without fertilizer-N, and sorghum (*Sorghum bicolor*) fertilized at two different fertilizer-N rates, low N (50 kg N ha^{-1}) and high N (150 kg N ha^{-1}). Overall, there were no significant differences in N_2O fluxes between the legume system (non N-fertilized soybean) and sorghum fertilized with synthetic N. There was also a negative correlation (R^2=0.86, p<0.01) between soil NO_3^--N and the C:N ratios of above-ground residues. During the post-crop fallow, N_2O fluxes from soybean and sorghum were significantly and positively correlated with soil moisture, NO_3^--N and dissolved organic carbon (DOC). The cumulative N_2O losses from unplanted control pots were nearly three times greater compared to either soybean or sorghum pots. These higher losses were associated with higher soil moisture and NO_3^--N contents in the control pots. In this experiment, I also attempted to quantify the below-ground N addition from soybean and sorghum using a ^{15}N leaf feeding technique. Unfortunately, the results for below-ground N estimations were inconclusive, principally because the methodology did not work for sorghum. However, the estimate for below-ground N for soybean, at 28% of the total plant N, appeared valid and closely paralleled estimates from other studies.

Experiment 3 was a laboratory incubation study designed to evaluate residue quality (%N, C:N ratio) effects on N_2O emissions and to evaluate the effects of the source of the residues, i.e. shoot *versus* root, on N_2O emissions. The same Black Vertosol soil used in the glasshouse experiments was amended with shoot or root residues of wheat, canola, soybean or sorghum and incubated at 25°C and 70% water filled pore space (WFPS) for a period of 56 days. The N_2O emissions patterns did not vary between shoot and root residues. Surprisingly, highest emissions in this experiment were associated with soils amended with high C:N ratio residues (wheat and sorghum roots) and, to some extent, lowest emissions were associated with low C:N ratio residues during the early stages of incubation (0–22 days). During this stage, there was a strong negative correlation between N_2O emissions and microbial respiration and a positive correlation between microbial respiration and DOC. These results suggest that residue decomposition negatively affected N_2O emissions during this early stage, presumably due to a combination of high background levels of NO_3^--N being denitrified and emitting N_2O, and different degrees of N immobilization affected by residue quality. In the later stages of the study (23–56 days), the high N, low C:N ratio residues of soybean shoot and canola roots had a three and two times higher N_2O flux, respectively, compared to the unamended control soil.

The final two experiments (Experiments 4 and 5) were laboratory incubation studies designed to evaluate the short-term effect of changing soil pH on N_2O emissions from the same acidic Black Vertosol. I used lime additions to raise the pH from 5.5 to 6.5, 7.4 and 7.7. In Experiment 4, the soils were treated without any added N and C (control), with both N (0.1 mg KNO_3-N g^{-1} dry soil) and C (0.3 mg glucose-C g^{-1} dry soil) added, or N alone added. Incubations lasted for 3 days at 70% WFPS. In Experiment 5, I used the acetylene inhibition technique at two soil moisture contents (60% and 80% WFPS) to examine the effects of changing soil pH on N_2O emissions and on the N_2O:(N_2O+N_2) ratio of the emitted gases. A naturally occurring alkaline Black Vertosol was also used in this experiment as a reference. Across the two experiments, highest N_2O emissions were observed at the natural pH (5.5) of the acidic Black Vertosol, with emissions progressively declining as the pH was increased to 6.5, 7.4, and 7.7. This pH effect was a combination of changes in denitrification rates coupled with an increase in the N_2O:(N_2O+N_2) emissions product ratio. Denitrification

potential in the naturally-alkaline Vertosol did not vary with that from naturally-acidic Vertosol either unlimed or limed at the higher soil moisture content. Results illustrated the potential of lowering N_2O emissions by 40−70% through liming of acid soils, with trends in these two experiments consistent across various substrate conditions and moisture contents.

To conclude, although fertilizer-N rates, residue sources and soil pH all influenced N_2O emissions, soil moisture appeared to be the dominant factor controlling the magnitude of N_2O emissions from this acidic Black Vertosol, which was inherently rich in both total and mineral N.

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List of Abbreviations

AGN	Above-ground nitrogen
AGR	Above-ground residues
BGN	Below-ground nitrogen
BGR	Below-ground residues
C	Carbon
C_2H_2	Acetylene
CO_2	Carbon dioxide
D	Day
DAS	Days after sowing
DOC	Dissolved organic carbon
HN	High nitrogen
KNO_3	Potassium nitrate
LN	Low nitrogen
N	Nitrogen
N_2	Gaseous nitrogen
^{15}N	Nitrogen isotope with the mass 15
N_2O	Nitrous oxide
NH_4^+	Ammonium
NO_3^-	Nitrate
NSW	New South Wales
ng	Nanogram
µg	Microgram
Tg	Teragram
w/w	Weight per weight
w/v	Weight per volume
K_2SO_4	Potassium sulphate
KCl	Potassium chloride