High nitrous oxide emissions from irrigated maize and barley in northern Victoria

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Abstract

Nitrous oxide (N_2O) emissions from agriculture are problematic from both a productivity and environmental perspective, representing the loss of a valuable nutrient and emission of a potent greenhouse gas. Key factors driving N_2O loss include high soil water (a surrogate for anaerobic conditions), soil mineral N availability, labile carbon and soil temperature. Given the likelihood of regular waterlogging and high rates of N fertiliser applied, the potential for N_2O emissions from irrigated cropping systems was assumed to be high. A trial (two replicates) was established in December 2013 to compare N_2O emissions from an irrigated maize crop grown under two rates of N fertiliser (265 and 360 kg N ha^{-1}). Fertiliser was applied throughout the season using a variety of methods including: banded at sowing, with irrigation water and topdressing. A second trial established in April 2014 measured N_2O emissions from irrigated barley grown on either wheat or faba bean stubbles. Measured emissions from both sites were extremely high (peak fluxes >2 kg N_2O-N $ha^{-1}day^{-1}$) following irrigation early in each season; possibly associated with re-wetting of the soil at a time when crop uptake of N would be lowest. Treatment differences were generally limited except for selected periods when emissions from faba bean stubbles were higher than wheat. The substantial emissions of N_2O measured highlights the significant greenhouse risk associated with these systems. This paper discusses these results including potential implications for reducing emissions in farming systems with high N input requirements which undergo regular waterlogging.

Key words

Nitrous oxide, irrigated cropping, nitrogen, barley, maize

Introduction

N_2O is a potent greenhouse gas with a global warming potential approximately 300 times that of carbon dioxide. The major source of N_2O in Australia is agricultural soils, representing 23% and 3.6% of the agricultural sector and national greenhouse footprints, respectively (Department of the Environment, 2014). While there are a complex range of microbial processes associated with the production and consumption of N_2O (Butterbach-Bahl et al, 2014), nitrification and denitrification are typically identified as the main contributors to N_2O release. The largest emissions of N_2O are typically associated with denitrification. Denitrification occurs when microbes within the soil utilise NO_3^- as an alternative electron acceptor in the absence of oxygen, reducing NO_3^- to di-nitrogen (N_2) with N_2O produced as an intermediary. Due to the requirement for anaerobic conditions, denitrification is usually associated with periods of waterlogging. Consequently, soil water filled pore space (WFPS%) is often used as a surrogate for such conditions with the ratio of denitrification to N_2O nominally peaking at approximately 60%. Nitrification occurs at WFPS of approximately 4060% and denitrification to N_2 at >70%, increasing progressively to 100% (Granli and Bøckman, 1994). N_2O fluxes have also been shown to be highly responsive to rewetting of dry soils when increased microbial respiration depresses oxygen levels, inducing anaerobic conditions (Ruser *et al*., 2006).

Agricultural soils which undergo regular wetting and drying cycles are at significant risk of N_2O loss where other factors such as availability of mineral N, labile carbon and soil temperature (all key contributors to the processes outlined above) are nonlimiting. It therefore follows that the irrigated cropping systems of northern Victoria, characterised by regular waterlogging, wetting and drying cycles and high rates of N fertiliser application, are at significant risk of N_2O loss. Mitigation of N_2O loss is often based upon better synchronising N supply with crop demand through altered rate, timing, placement and form of application; often termed the four R's approach (IPNI, 2015). Given the high yield potential and correspondingly high N input requirements of irrigated cropping systems, achieving the four R's is particularly important. During 2013/14 two demonstration trials were undertaken in northern Victoria which aimed to quantify the magnitude and seasonal dynamics of N_2O loss in such systems. This paper presents these results in the broader context of managing N_2O loss in high intensity irrigated production systems.

Methods

Site establishment and experimental design

In December 2013 a demonstration scale trial (2 replicates) was established within a commercial paddock at Koorop in the northern Victoria irrigation region to compare N_2O emissions from an irrigated maize crop grown with varying rates of N fertiliser inputs (265.5 kg N/ha and 360.5 kg N/ha). N was applied at sowing as a mixture of DAP and urea; further applications of N to the low N treatment were applied with irrigation water and the balance being applied as topdressed urea for the high N treatment. In April 2014 a second trial (2 replicates) was established within a commercial barley paddock at Kerang, also in the northern Victoria irrigation region. This site was part of a broader crop sequencing trial enabling a comparison of N_2O emissions from irrigated barley grown on either faba bean or wheat stubbles. N was applied as topdressed urea. Timing and rates of irrigation and fertiliser application are outlined in Table 1

Table 1. Irrigation and N applied to low and high N treatments for maize grown at Koorop, December 2013 to March 2014 (left). Irrigation and N applied to barley grown on either wheat or faba bean stubble at Kerang during 2014 (right).

*Further irrigation and N was applied outside the N_2O monitoring period (total of 2 ML/ha and 25 kg N/ha).

Timing	Irrigation applied (ML/ha)	N applied (kg/ha)		Timing	Irrigation applied (ML/ha)	N applied (kg/ha)	
		Low N	High N			Wheat stubble	Faba bean stubble
12-Dec 13	1	138	138	9-Apr 14	2	20	-
30-Dec 13	0.6		25	30-Jun 14	-	50	50
14-Jan 14	0.6	42.5	42.5	23-Jul 14	-	50	25
29-Jan 14	0.6	42.5	77.5	25-Aug 14	1	-	-
10-Feb 14	0.6	-	35	18-Sept 14	0.8	-	-
25-Feb 14	0.6	42.5	42.5	13-Oct 14	0.8	-	-
Total	4.0*	265.5	360.5*	Total	4.6	120	75

Monitoring for N_2O flux

Nitrous oxide measurements were taken using static chambers (Harris *et al*., 2013) with duplicate chambers placed in each plot. Samples were collected from the chamber headspace over a period of one hour (three samples) on each sampling event. Air temperature within the chambers was measured at the time of sampling and lids were removed from the chambers between sampling days. Samples were analysed by gas chromatography. Sampling was undertaken on a total of 18 days for the maize site (between 12-Dec 2013 and 4-Mar 2014) and 12 days for the barley site (between 9-Apr and 20-Oct 2014). Sampling was organised into clusters of three days designed to coincide with irrigation, fertiliser applications and or rainfall events, with sampling undertaken prior to these events, 1-4 days later and then 1-2 weeks after the event. The purpose of this sampling regime was to identify the general trend in emissions across the season and to capture peak fluxes in response to altered soil water/ anaerobicity and or mineral N supply. Fluxes were calculated from the linear increase in gas density within the chamber headspace over time after being adjusted for chamber volume.

Results

N_2O emissions from irrigated maize in response to varying N fertiliser rates

Measured daily N_2O flux rates at Koorop were extremely high (in some cases > 2kg N_2O-N/ha/day) early in the maize growing season following irrigation events (Figure 1). In subsequent days (typically 6-7 days), fluxes fell to <20 g N_2O-N/ha/day. Over the season, emissions trended strongly downwards, with the most extreme events associated with initial re-wetting of the soil at sowing. The relationship between N application rate and N_2O flux was not consistent, characterised by high variability with the lower N rate sometimes resulting in higher daily flux rates contrary to expectation. We hypothesise that this observation may be indicative of the two N rates tested being relatively similar, particularly early in the season when the highest fluxes were measured. Given the demonstration focus of this trial, key measurements (soil mineral N, soil water, labile carbon) were not taken, thus the mechanism cannot be resolved.

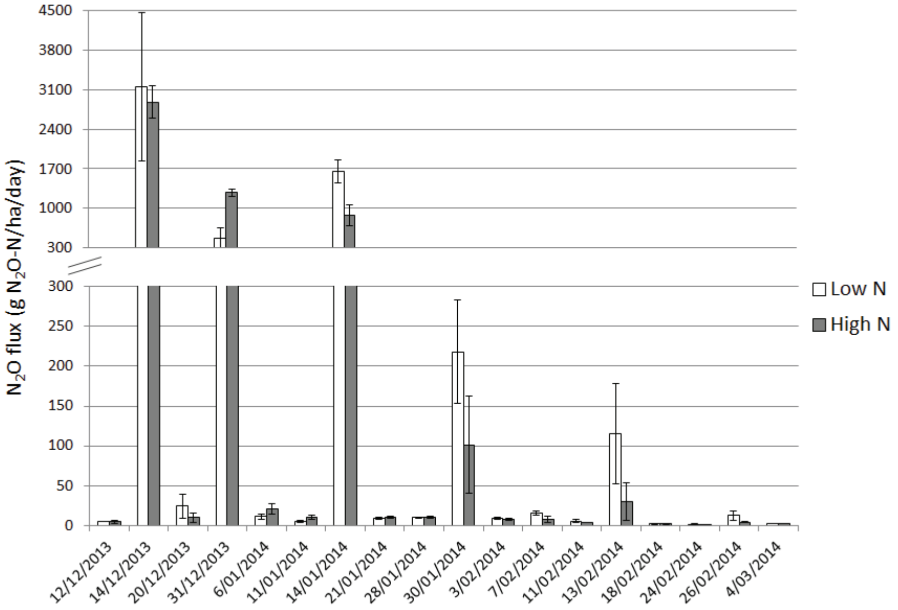

Figure 1. N_2O flux from maize grown at Koorop with varying rates of N fertiliser December 2013 to March 2014. Bars represent standard error.

N_2O emissions from irrigated barley in response to varying previous crop

Daily N_2O flux rates at Kerang were also extremely high early in the barley growing season (in some instances >2 kg N_2O-N/ha/day). Similar to the irrigated maize site, rates of N_2O emissions were strongly related to irrigation events. With the exception of the initial spike in emissions following irrigation at sowing, peak fluxes tended to be lower for the rest of the season (Figure 2). Fluxes from the faba bean treatment were generally higher than those from the wheat stubble. Soil testing on 12-July indicated significantly higher (84 kg N/ha versus 37 kg N/ha) mineral N from 0-60cm depth. While this data was not measured exclusively from the topsoil, where the majority of N_2O producing activity would be expected, it nonetheless illustrates a significant increase in mineral N from mineralisation of faba bean residues. It was expected that N_2O flux was limited by reduced availability of mineral N in the wheat stubble treatment despite the addition of extra N fertiliser. The difference in N application rate between treatments was moderate with the wheat stubble receiving 120 kg N/ha versus 75 kg N/ha for the faba bean stubble.

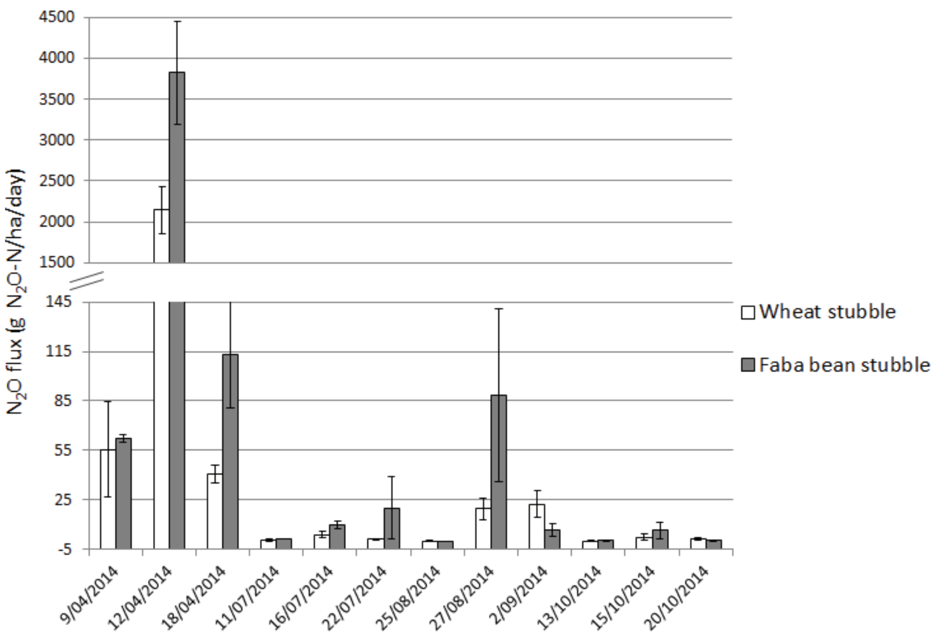

Figure 2. N_2O flux from barley grown at Kerang following either barley or faba beans in the previous winter season. Bars represent standard error.

Implications of these findings for future research and the irrigated cropping industry

The magnitude of N_2O fluxes measured following early season irrigation events highlights the significant greenhouse gas emissions associated with irrigated cropping systems. Ruser *et al*. (2006) also observed significant N_2O flux following rewetting of dry soils with small N_2:N_2O ratios at WFPS of up to 90%, indicating large scale incomplete denitrification (N_2O rather than N_2). It was suggested that these initial spikes may have been related to stimulation of microbial activity, leading to increased O_2 consumption causing anaerobic conditions favourable to denitrification. Furthermore Letey *et al*. (1980) measured low N_2:N_2O ratios immediately following rewetting which fell significantly over a period of 8 days. It was suggested that a possible explanation for this was a mismatch between the time taken for initiation of NO_3^- reduction and the production of N_2O reductase (the enzyme responsible for reducing N_2O to N_2).

Our findings pose a significant challenge to policy makers and industry in relation to irrigated cropping systems. On the one hand, high productivity demands significant N and water inputs, often early in the season. Conversely our data suggests that this can produce significant environmental risk. The question is whether there are feasible options to 1) decrease the N_2O effect of initial rewetting and 2) better match N supply to crop demand. Tools and products are available to slow N cycling within the soil (e.g. enhanced efficiency fertilisers), but predicting N supply from mineralisation to fine tune fertiliser rates remains a challenge. Managing the risk of rewetting appears to be more difficult; one option might be to avoid irrigating at sowing, halting germination until rainfall is received and delaying irrigation until later in the season when the soil is already moist. This an unlikely option for summer crops given that long term median rainfall at Kerang is approximately 15 mm/month during summer (BOM, 2015) and also contradicts the need for early sowing to achieve high productivity. There are few easy answers when trying to manage N_2O loss from intensive industries where small mismatches in water and N supply can result in significant emissions.

Conclusion

Nitrous oxide emissions measured as part of these demonstration focussed trials have highlighted a significant greenhouse gas risk from irrigated cropping in Victoria, in particular associated with early season irrigation events. Mitigation through manipulating availability of mineral N was attempted, but in the limited examples tested, adding extra N fertiliser did not necessarily result in higher emissions. However this was likely complicated by the relative similarity of N rates tested. The sheer magnitude of emissions measured following irrigation early in each season poses a significant challenge to both researchers and the industry to find ways of avoiding such high fluxes while maintaining the high levels of productivity associated with irrigated cropping.

References

Butterbach-Bahl K., Baggs E.M., Dannenmann M., Kiese R., Zechmeister-Boltenstern S. (2013) Nitrous oxide emissions from soils: How well do we understand the processes and their controls? Philosophical Transactions of the Royal Society B: *Biological Sciences* **368.**

Bureau of Meteorology 2015, *Climate data online*, viewed 11 May, 2015, http://www.bom.gov.au/climate/data/?ref=ftr.

Department of the Environment 2014, *National inventory report 2012: Volume 1*, viewed 12 February, 2015, http://www.environment.gov.au

Granli T., Bøckman O.C. (1994) Nitrous oxide from agriculture. *Norwegian Journal of Agricultural Sciences Supplement* **12**,7–128.

Harris R., Officer S., Hill P., Armstrong R., Fogarty K., Zollinger R., Phelan A. (2013) Can nitrogen fertiliser and nitrification inhibitor management influence N_2O losses from high rainfall cropping systems in South Eastern Australia? *Nutrient Cycling in Agroecosystems* **95**:269-285.

International Plant Nutrition Institute 2015, 4R nutrient stewardship, viewed 9 May, 2015, http://www.ipni.net/4R. [Accessed 09 May 15].

Letey J., Valoras N., Hadas A., Focht D.D. (1980) Effect of Air-filled Porosity, Nitrate Concentration, and Time on the Ratio of N_2O/N_2 Evolution During Denitrification. *Journal of Environmental Quality* **2**:227-231.

Ruser R., Flessa H., Russow R., Schmidt G., Buegger F., Munch J.C. (2006) Emission of N_2O, N_2 and CO2 from soil fertilized with nitrate: effect of compaction, soil moisture and rewetting. *Soil Biology and Biochemistry* **38**:263-274.