Management strategies for improved productivity and reduced nitrous oxide emissions for wheat following a legume and canola

The following article is taken from the final report of a Department of Agriculture and Water Resources project, Management Strategies for Improved Productivity and Reduced Nitrous Oxide Emissions*, run in the Riverine Plains region and in the mid North of South Australia at the Hart Field Site during the past three years.*

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Summary

Nitrous oxide emissions (N_2O) from Australian grain cropping systems are highly variable due to the large variations in soil, climate and management practices. Overall this research confirms that N_2O emissions from dryland cropping systems in the Riverine Plains is at the low end of the range for temperate climatic zones in eastern Australia.

In the current study, N_2O emissions and crop productivity were assessed under a range of nitrogen (N) management strategies. Six nitrogen treatments were assessed, including combinations of nitrogen rate (0, 40 or 80 kg/ha), application timing (incorporated by sowing (IBS) or first node (GS31) of wheat), a nitrification inhibitor (DMPP) and real time crop nitrogen prediction using a Greenseeker®. These six nitrogen strategies were applied to wheat sown after canola or a legume.

In general, across the three seasons (2014–16), N_2O emissions from fertiliser applications were slightly elevated compared with the control. In some seasons however, N_2O emissions were increased above background levels and cumulative values were at the higher end of those reported from dryland farming (>2kg or 2000g N_2O-N/ha/season). High emissions were measured from both IBS and first node (GS31) application timings, depending on the seasonal conditions. Seasons dominated by early heavy rainfall favoured in-season nitrogen application for reduced N_2O emissions. However, these treatments often did not result in the highest grain yield or quality. It is important to note that cumulative emissions were only assessed over the growing season to look at in-season fertiliser nitrogen management. Annual values may have been higher if summer fallow emissions were also assessed prior to sowing.

Background

Nitrous oxide (N_2O) is an important greenhouse gas due to its high global warming potential (GWP), which means it can trap heat in the atmosphere, contributing to global warming. It is produced by soil microbial activity through denitrification processes, and is increased in the presence of nitrogen fertilisers, high levels of organic residues and livestock waste, especially when the soil conditions are anaerobic (void of oxygen) such as occurs with waterlogging. Recent research has shown there is a range of reduction strategies that may benefit growers both environmentally and economically. The objective of this research was to measure and demonstrate on-farm strategies to reduce N_2O emissions from cropping soil.

Soils also release dinitrogen (N_2) gas through denitrification, however this is difficult to measure as dinitrogen is naturally occurring in the Earth's atmosphere at relatively high concentrations. In comparison, as N_2O concentrations in the atmosphere are much lower, it is easier to detect changes in N_2O emissions due to denitrification under different management strategies. In general, the release of N_2 from soil can be 20–30 times greater than nitrogen lost through N_2O, though the exact relationship between the two gases depends on the water content of the soil. This means the total amount of nitrogen lost from soil through gas release could be 20–30 times greater than that measured through N_2O emissions.

As the field trials for this project were completed during 2016, this report presents a summary of results from three years of field trials.

Aim

The aim of the *Management Strategies for Improved Productivity and Reduced Nitrous Oxide Emissions* project, funded by the Department of Agriculture and Water Resources, Action on the Ground program, was to



measure and demonstrate on-farm strategies to reduce N_2O emissions and improve nitrogen use efficiency.

Method

This project measured the N_2O emissions and crop productivity under a range of nitrogen management strategies in wheat crops from 2014–16.

Trials were carried out at Yarrawonga, Victoria and Hart, South Australia for three seasons. The actual location of the trial site was relocated each year, as each year required a wheat crop to be sown into canola or a legume. In order for this to be done, in the season prior to the trials being established, a paddock at each location (Yarrawonga and Hart) was split in half. One half of the paddock was sown to canola, the other to a legume (peas at Yarrawonga). The following year, this paddock was all sown to wheat, with the different nitrogen treatments applied.

Due to the logistics of such a trial, the preceding canola and legume could not be sown within an integrated statistically robust design. Rather, the wheat trials following canola or legume were established side-by-side. This means a direct statistical comparison of the nitrogen treatments in wheat following canola or legume could not be done. Therefore, the results from each rotation are presented separately.

Six nitrogen treatments were assessed including combinations of nitrogen rates (0, 40 or 80 kg/ha), which were either incorporated by sowing (IBS) or applied at first node (GS31). Urea coated with a nitrification inhibitor was also evaluated, which is marketed as Entec® (DMPP; 3, 4 dimethylpyrazole phosphate), with a final treatment where the rate and timing of nitrogen application was determined by in-crop normalised difference vegetative index (NDVI) measurements, using a Greenseeker® (Table 1).

While trials were carried out at both Yarrawonga and Hart, only the Yarrawonga results are presented in this report as both sites displayed similar trends, with the Yarrawonga results being most relevant to this region.

Results

Nitrous oxide emissions

The trials showed that nitrogen fertiliser applications sometimes resulted in increased N_2O emissions compared to the control (nil nitrogen plots), however this was very seasonally dependent (Table 2; Figure 1).

In 2014 heavy rainfall early in the season, shortly after sowing, resulted in transient waterlogging at the Yarrawonga site (Figure 2). This corresponded to high

TABLE 1 Nitrogen rates and application timing for wheat trials located at Yarrawonga, from 2014–16

Treatment No.	Nitrogen rate and application timing
1	Nil nitrogen applied (control)
2	#80kg N/ha as urea incorporated by sowing (IBS)
3	#40kg N/ha applied as urea at first node (GS31) of the wheat crop
4	#80kg N/ha applied as urea at first node (GS31) of the wheat crop
5	#80kg N/ha applied urea + DMPP* at first node (GS31) of the wheat crop — urea coated with nitrification inhibitor, commercially available as Entec
6	**Real time tactical (RTT) — post-emergent nitrogen application determined using a Greenseeker to measure crop NDVI. Applied as one or two split nitrogen applications post start of stem elongation (GS30) **Wheat following canola** (applied as single or two split applications in-season): 2014 – 59kg N/ha 2015 – 35kg N/ha 2016 – 44kg N/ha. **Wheat following legume** (applied as single or two split applications in-season): 2014 – 53kg N/ha 2015 – 24kg N/ha 2016 – 15kg N/ha.

Due to wet conditions at Yarrawonga during 2014, all 80kg N/ha applications were increased to 100kg N/ha and 40kg N/ha applications were increased to 50kg N/ha at the GS31 application time.

* DMPP = 3, 4 dimethylpyrazole phosphate.

** Greenseeker® NDVI measures the combined effects of chlorophyll concentration and total biomass of the crop. Nitrogen application rate was calculated using a NDVI response index (RI) and yield potential estimates.

TABLE 2 Cumulative N_2O emissions for nil, 80kg N/ha applied IBS or first node (GS31) for wheat following peas or canola at Yarrawonga in 2014–16

Previous crop	Treatment	Yarrawonga 2014	2015	2016
		g N_2O-N/ha/season		
Canola	Nil	212^{b}	109^{c}	1779^{a}
	80kg/ha IBS	1922^{a}	301^{a}	2443^{a}
	80kg/ha @ GS31	340^{b}	197^{b}	2556^{a}
	80kg @ GS31 + DMPP	-	-	1872^{a}
	Mean	**82**	**202**	**2163**
	LSD (P≤0.05)	1339	50	1189
Legume	Nil	287^{a}	78^{b}	809^{b}
	80kg/ha IBS	1686^{a}	198^{a}	2738^{a}
	80kg/ha@ GS31	390^{a}	151^{ab}	2052^{ab}
	80kg @ GS31 + DMPP	-	-	1135^{b}
	Mean	**785**	**142**	**2378**
	LSD (P≤0.05)	1505	73	1262

Figures followed by different letters are regarded as statistically significant.

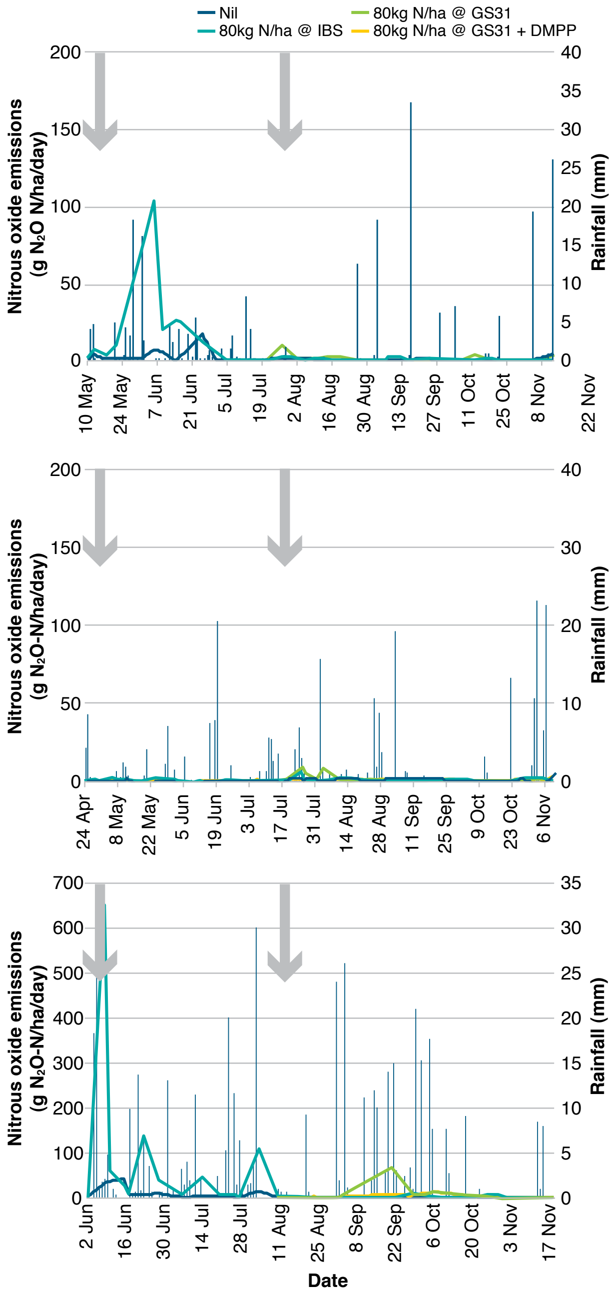

FIGURE 1 Nitrous oxide emissions for nil, IBS and GS31 nitrogen applications for wheat sown after a legume in 2014 (top), 2015 (mid) and 2016 (bottom) at Yarrawonga*

* The GS31 + DMPP emissions were also measured in 2016. The grey arrows indicate the date of nitrogen fertiliser application. Please note the change in scale for N_2O emissions in 2016.

daily N_2O emissions, with the highest measurements observed where fertiliser nitrogen was applied IBS (Figure 1). However the yields from the IBS nitrogen were significantly higher than other treatments, despite N_2O emissions that were five times greater than nitrogen applied at first node (GS31) (Table 3). This shows that nitrogen management for grain yield, and for reduced N_2O emissions, cannot always be achieved.

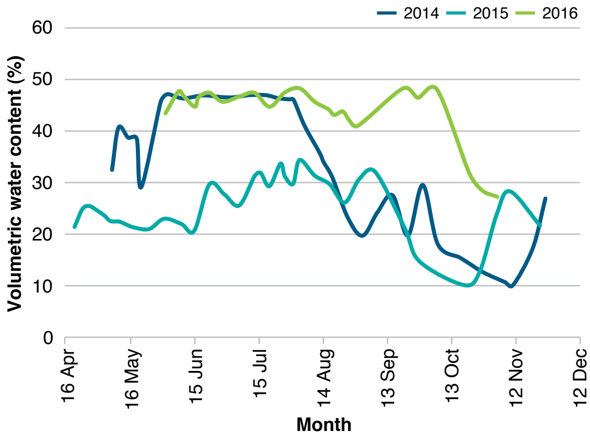

FIGURE 2 Volumetric water content to a depth of 12cm for the growing season at Yarrawonga from 2014–16

Similarly, the wet 2016 season saw cumulative N_2O emissions at the high end of the range reported for dryland cropping systems (>2000g N_2O-N/ha/season). Total N_2O emissions ranged from 809–2738g N_2O-N/ha/season for the nil and 80kg N/ha applied treatments (Table 2). Immediately after sowing, N_2O emissions were highest at 60 g N_2O-N/ha/day (Figure 1). This was followed by another four 'peak' emission periods, which occurred during late June through to mid-September 2016. These high emission periods corresponded to high rainfall and waterlogged soil conditions (Figure 3).

The volumetric water content was consistently high at 40–50% with twice the number of days of waterlogging in 2016 compared with 2014, measured from May through to mid-October (Figure 2). Adding to this issue, the low nitrogen demand from the patchy and poorly-established wheat crop (counts ranged from 0–70 plants/m^2 at two leaf stage (GS12)) would have increased the amount of fertiliser nitrogen available for loss. In general, N_2O emissions were high regardless if nitrogen was applied IBS or at first node (GS31) in the 2016 season. When compared with crop performance, the most economic nitrogen strategy in 2016 was for growers to apply no nitrogen in terms of both crop yield and N_2O emissions.

In contrast, volumetric water content during 2015 never rose above 30% (Figure 2) and emissions were minimal, although there was a significant increase associated with upfront nitrogen following both canola and peas.

There was evidence the nitrification inhibitor Entec reduced N_2O emissions. When used at first node (GS31) during 2016 it produced significantly less N_2O than the IBS applied nitrogen, although this reduction in



TABLE 3 Grain yield and protein levels for nitrogen treatments applied to wheat following canola or a legume at Yarrawonga from 2014–16

Previous crop	Nitrogen rate	2014 Yield (t/ha)	2014 Protein (%)	2015 Yield (t/ha)	2015 Protein (%)	2016 Yield (t/ha)	2016 Protein %
Canola	Nil	5.45^{b}	8.6^{c}	4.04^{b}	8.5^{d}	1.35^{b}	8.6
	#80kg @ IBS	6.75^{a}	11.0^{ab}	4.31^{a}	11.3^{bc}	2.11^{a}	9.6
	40kg @ GS31	5.92^{b}	10.1^{b}	4.24^{ab}	10.3^{cd}	1.88^{ab}	9.2
	#80kg @ GS31	5.68^{b}	11.7^{a}	4.11^{ab}	13.4^{a}	2.13^{a}	10.3
	#80kg @ GS31 + DMPP	5.48^{b}	11.1^{ab}	4.24^{ab}	12.1^{ab}	2.13^{a}	10.0
	Tactical nitrogen	5.90^{b}	11.2^{ab}	4.28^{ab}	9.9^{cd}	1.92^{ab}	8.7
	Mean	**5.86**	**10.6**	**4.20**	**10.9**	**1.90**	**9.3**
	LSD (P≤0.05)	0.60	1.4	0.27	1.8	0.68	n/a
Legume	Nil	5.28^{b}	8.2^{c}	4.42^{ab}	10.6^{d}	1.93^{a}	8.2
	#80kg @ IBS	6.74^{a}	11.1^{a}	4.36^{ab}	13.7^{ab}	2.32^{a}	9.6
	40kg @ GS31	5.84^{b}	10.3^{ab}	4.29^{ab}	12.3^{c}	1.52^{a}	9.3
	#80kg @ GS31	6.03^{ab}	11.2^{a}	4.04^{b}	14.5^{a}	2.43^{a}	10.3
	#80kg @ GS31 + DMPP	5.70^{b}	10.5^{ab}	4.47^{a}	12.9^{bc}	2.00^{a}	10.3
	Tactical nitrogen	5.58^{b}	10.0^{b}	4.49^{a}	12.5^{bc}	1.91^{a}	8.6
	Mean	**5.86**	**10.2**	**4.35**	**12.8**	**2.02**	**9.4**
	LSD (P≤0.05)	0.77	1.1	0.41	1.2	1.07	n/a

* In 2014 only the 40 and 80kg N/ha treatments were increased to 50 and 100kg N/ha, respectively at GS31.
# Total nitrogen rate applied for 2014, 2015, and 2016 as one or two split applications in-season.
n/a = not statistically analysed due to the combination of replicate samples for protein assessment.

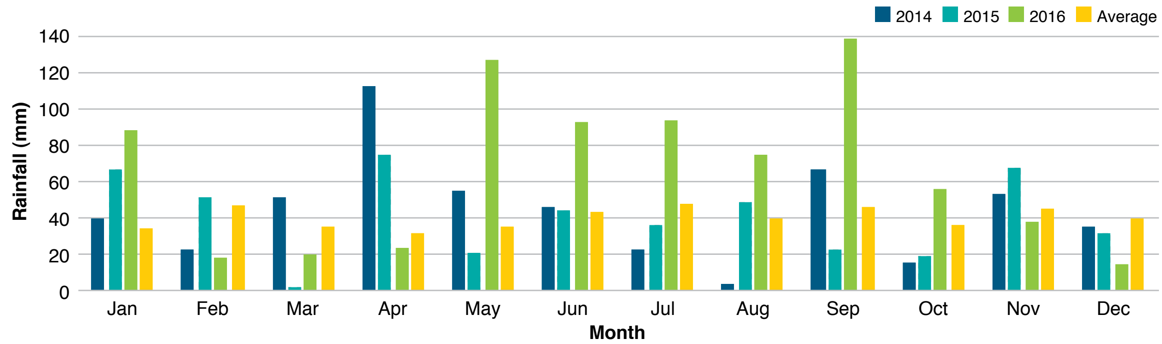

FIGURE 3 Annual rainfall for Yarrawonga from 2014–16 including historic long-term average rainfall (based on 100 years of records)

emissions was not always significantly lower than urea when applied at the same growth stage (GS31).

Though emissions were not measured in the tactical nitrogen treatment there was evidence that using crop sensor technology allowed nitrogen levels to be reduced without affecting crop yield. The use of the Greenseeker crop sensor allowed better quantification of the nitrogen available in the soil during spring and for nitrogen rates to better match crop demand.

As similar trends in emissions were measured when wheat was sown after canola, those results are not displayed in Figure 1.

How the results affect our overall approach with nitrogen

This study highlighted that growers can try to synchronise nitrogen supply with peak crop nitrogen demand to encourage greater fertiliser uptake and potentially reduce N_2O losses. However, while this strategy was beneficial for grain yield and quality, in some seasons it was not optimal for reducing N_2O emissions due to waterlogged conditions. There was evidence that RTT nitrogen prediction, using Greenseeker technology allowed the residual nitrogen from the previous crop to be better identified. The RTT treatment using the Greenseeker allows the crop itself to be the indicator of nitrogen uptake rather than depending on a soil test taken earlier in the season. NDVI measurements taken at the start of stem elongation (GS30) showed that more soil nitrogen was available to satisfy crop yield potential than was originally thought at sowing, and this allowed reduced fertiliser application without compromising grain yield.

There are some general strategies to assist growers with nitrogen management decisions to maximise crop uptake and reduce the potential for N_2O emissions. If the forecast is for a dry to average season the results suggest minimising up-front nitrogen additions, which was of benefit during 2015.

In the project, delaying nitrogen applications maintained grain yield, while protein was increased compared with IBS only applications (Table 3). The strategy of delaying nitrogen applications allows growers to make fertiliser decisions as the season progresses with more accurate forecasting and when crop demand for nitrogen is higher (e.g. stem elongation phases). If the forecast is for a wet season, there will be higher potential for nitrogen losses. In this scenario applying more nitrogen upfront to get the crop through 'wet' periods may be the best strategy in terms of grain yield and quality, when there are limited opportunities to spread fertiliser in season, but may result in elevated N_2O losses.

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