Nitrous oxide emissions and carbon balance of different N management systems

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Abstract

Under-fertilisation of nitrogen (N) in dryland grain crops in southern Australia has led to a significant yield gap and soil organic matter depletion. Growers use a range of different methods for deciding fertiliser-N application rate, such as the APSIM-based Yield Prophet® (YP) decision system and the N bank (NB) system which sets an optimum partial N supply target for an environment. We monitored nitrous oxide (N_2O) emission and agronomic performance of the different decision-making systems against the national average (NA) application of 45 kg fertiliser-N/ha and a NIL control in a field experiment at Dookie in Victoria. The NB system applied 125 kg fertiliser-N/ha to a wheat crop, whilst YP at 25% probability only applied 16 kg fertiliser-N/ha due to high starting soil mineral N and low growing season rainfall up to the time of decision making. The NB system achieved the highest grain yield (7.1 t/ha), followed by YP 25% (5.7 t/ha), NA (5.8 t/ha) and NIL (4.9 t/ha) treatments (at 12% grain moisture, $P<0.01$, LSD=1.1). The NB system also had the highest N_2O emission during the season (1.7 kg compared to 0.8 kg N_2O-N/ha in NA). N_2O emissions in other treatments were similar to NA. However, the NB system returned an additional 0.5 t/ha carbon and 13 kg/ha N in above ground residue to plots compared to NA, and maintained close to neutral (-3 kg N/ha) partial N balance compared to -52 and -76 kg/ha in NA and YP, respectively, indicating the possibility of soil carbon loss as CO_2 in NA and YP systems.

Keywords

Nitrogen management, Grain Crops, Nitrous oxide, Carbon Balance

Introduction

Estimation of fertiliser nitrogen (N) requirement in dryland grain crops in southern Australia is notoriously difficult because of the highly variable seasonal rainfall, which leads to under-fertilisation and a significant yield gap. Average annual wheat yield (1.71 t/ha) is 50% of water limited yield potential and nitrogen is the single biggest yield limiting factor (Hochman and Horan, 2018). The national average (NA) N rate is 45 kg/ha in Australian dryland cropping system. Considering that 40 kg N is required to produce 1 t/ha wheat, the NA rate is not enough to achieve water limited yield potential in most seasons (Hochman and Horan, 2018).

Growers use a range of different methods for deciding N fertiliser application rate, such as the APSIM-based Yield Prophet® (YP) decision support system which provides probability of different yield outcomes for a season (Hochman et al., 2009). As yield probabilities in the YP system relies on future rainfall (amongst other parameters), there is a risk of over or under fertilisation. In contrast, the N bank (NB) system sets an optimum N supply target (pre-sowing soil profile mineral N+fertiliser) for an environment which does not vary seasonally (Meier et al., 2021). The NB system pose the risk of over fertilisation in low yielding seasons but the risk of under fertilisation in high yielding seasons is low. The NB system relies on the assumption that the majority of unused N in a low yielding season is available for the following crop, meaning that the over fertilisation is not a lost cost (Smith et al., 2019). On one hand, over fertilisation of N may lead to significant emissions of nitrous oxide (N_2O), a greenhouse gas with 273 times higher global warming potential than carbon dioxide (Forster et al., 2021). On the other hand, the extra N in soil allows microbes to sequester C which increases soil organic matter (Kirkby et al., 2016; Kirkby et al., 2014). We investigated different N management systems in their ability to close grain yield gaps and maintain C and N balance in a field experiment in Curyo, Victoria and the first five years of data showed that both N bank and YP decision-making systems can profitably close grain yield gaps in Australian dryland cropping (Pandey et al., 2024). This paper focusses on nitrous oxide emissions and carbon balance measured in one season of the experiment conducted in Dookie, Victoria.

Methods

Site and experiment management

The field experiment was established in 2022 in the research farm of Dookie campus, The University of Melbourne in north central Victoria. This study presents data from the 2023 season. Soil at the site is brown Dermosol with loam topsoil (0-20cm) and clay subsoil (20-160cm). The site has near neutral topsoil pH (6.5) and alkaline subsoil pH (>8). Total C and N in the top 10 cm is 1.3% and 0.1%, respectively. The site receives 548 mm average annual rainfall (Bureau of Meteorology station number 081013).

The field experiment was a randomised complete block design with four replicates. Wheat cv. RGT Zanzibar was sown on 4 May 2023. Each replicate included four adjacent plots of 1.5 m × 10 m. Each plot included 6 crops rows with 25 cm row spacing. The treatments included were NB, YP at 25% yield probability, NA and a Nil control. All treatments, including Nil, received 10 kg N/ha at sowing in the form of monoammonium phosphate. The N bank target was 275 kg/ha N (soil mineral N at sowing to 1 m depth+fertiliser N input) in the NB treatment. This target was set to supply enough N appropriate for the environment to achieve water limited potential yield in most seasons. Soil cores were collected before sowing to 1 m depth and segmented to 0-0.1, 0.1-0.4, 0.4-0.7 and 0.7-1.0 m before drying at 40 °C, sieving to <2mm and analysing for mineral N. Soil mineral N to 1 m depth at sowing was 140 kg/ha, so we top-dressed 125 kg N/ha to achieve the 275 kg N/ha target. Yield Prophet® uses a combination of climatic, soil and management related data to generate yield forecast at different level of probabilities when the fertiliser decision is made (Hochman et al., 2009). We used YP at 25% yield probability as a treatment for this study. YP at 25% probability only applied 16 kg N/ha (in addition to the stater N) due to high starting soil mineral N and low growing season rainfall up to the time of decision making. NA received 45 kg N/ha in addition to the starter N. Urea was top-dressed when wheat was at early stem elongation (SCDS N0 to N2, Celestina et al., 2023). Weeds, disease and nutrient deficiencies (except N) were managed as per current best practice.

Crop, soil and gas sampling and data analysis

Above ground biomass and grain yield was measured by hand harvesting 0.5 m^2 in the third plot amongst the four adjacent plots in each range/block before drying at 70 ºC for 48 hours, weighing for biomass weight and threshing for grain weight. Grain and straw samples were analysed separately for N and C content using the total combustion method. To monitor N_2O emissions, stainless steel base of 15 cm height (50 cm L × 50 cm W) was inserted 7 cm into the soil in each treatment. The steel base included two crop rows. On each gas sampling day a top chamber (50 cm L, 50 cm W and 25 cm H) with rubber seal was clamped on the steel base and samples collected at 0, 45 and 90 minutes after chamber closure and injected into pre-evacuated exetainer vials. Extension chambers (50 cm H) were used when wheat plant began to elongate. Gas sampling started 1 week after fertiliser application and continued until crop harvest. Samples were collected ~weekly starting at 11am on each sampling event for three months (13 sampling events in total). The sample vials were analysed for N_2O by gas chromatography (Agilent 7890A) using an electron capture detector. The N_2O flux was calculated from the linear regression of N_2O concentration over time (Venterea et al., 2020). All data were analysed in GenStat 22nd Edition. Biomass, grain yield and cumulative N_2O emissions were analysed using mixed linear models with treatment as fixed and block as random effects.

Results

The NB system achieved the highest grain yield, followed by YP 25%, NA and Nil treatments (Table 1). Cumulative N_2O emissions had a strong positive linear relationship with fertiliser-N rates (Figure 1). The NB system had the highest N_2O emission during the season (1.7 kg compared to 0.8 kg N_2O-N/ha in NA, Figure 1). N_2O emissions in other treatments were similar to NA. However, the NB system returned an additional 1.4 t/ha above ground crop residue which added additional 0.5 t/ha carbon to the plot compared to NA (Table 1). The NB system also maintained close to neutral (-3 kg N/ha) partial N balance compared to -52 and -76 kg/ha in NA and YP, respectively (Table 1).

Table 1. Effect of N management systems on grain yield, residue returned to plots, carbon returned in crop residue and N balance.

Treatments	Fertiliser N input (kg/ha)	Grain yield (t/ha)	Residue returned (t/ha)	Total C returned (t/ha)	Grain N export (kg/ha)	Partial N balance (kg/ha)
Nil	10	4.9	5.8	2.3	77	-67
NA	55	5.8	6.8	2.8	107	-52
YP 25%	26	5.7	6.8	2.8	102	-76
NB	135	7.1	8.2	3.3	138	-3
F Pr.		0.01	0.026	0.03	<0.001	<0.001
LSD		1.1	1.3	0.5	22.9	22.9

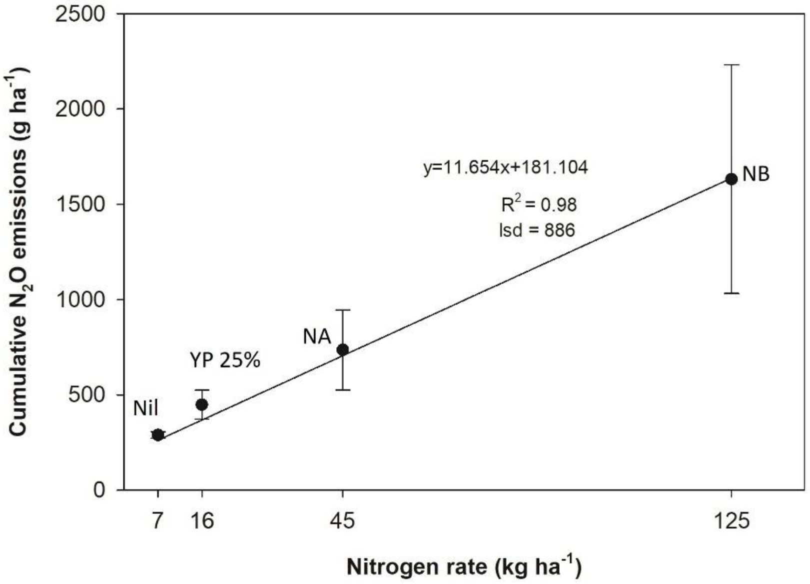

Figure 1. Relationship between cumulative N_2O emissions (g/ha) and fertiliser-N rates (kg/ha).

Conclusions

This study shows that YP system risks underestimation (or overestimation) of yield and thus the N requirement for crops. The season was predicted to be dry (49% chance of unusually dry season). Therefore, YP at 25% probably predicted lower water limited yield potential and N requirement for the crop. Dookie received 79 mm rainfall during the first week of October which increased the water limited yield potential for the season. As NB system has a fixed N target regardless of the seasonal forecast, the system was able to achieve significantly higher grain yield compared to other treatments. The higher N application in NB system increased N_2O emissions but the system returned higher C in crop residue to the plots and maintained near neutral N balance which indicates that the system can maintain or increase soil organic matter, whereas YP and NA systems pose the risk of soil organic matter decline due to the low nutrient (N) availability for soil microbes (Kirkby et al., 2016). Using a long-term experiment, Sevenster et al. (2024) demonstrated that C loss due to low N input can be double the greenhouse intensity of adequate N input. So, it is essential to balance N input to maximise yield and achieve C balance.

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