Agriculture, Ecosystems and Environment 253 (2018) 82–89

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

On-farm trial on the effectiveness of the nitrification inhibitor DMPP indicates no benefits under commercial Australian farming practices

Philipp A. Nauer[a,*], Benedikt J. Fest[b], Luke Visser[c], Stefan K. Arndt[a]

[a] School of Ecosystem and Forest Sciences, The University of Melbourne, 500 Yarra Boulevard, Richmond, Victoria 3121, Australia
[b] School of BioSciences, The University of Melbourne, Parkville, Victoria 3010, Australia
[c] Murray Goulburn Co-Operative, 19 Kiewa East Road, Kiewa, Victoria 3691, Australia

ARTICLE INFO

Keywords:
Nitrification inhibitor
DMPP
On-farm trial
Nitrous oxide
Crop yield
Pasture yield

ABSTRACT

The trend of increasing nitrogen (N) fertilisation in commercial agriculture demands mitigation of negative impacts on the environment, such as emissions of the potent greenhouse gas nitrous oxide (N_2O). Laboratory and controlled field experiments have demonstrated that the nitrification inhibitor 3,4-Dimethylpyrazole phosphate (DMPP) has the potential to effectively mitigate N_2O emissions from dairy pasture and crop farming, and may increase yields. Yet, this has not been investigated in on-farm research trials under commercial production conditions. During the winter growing seasons 2014–2016 we performed an on-farm trial on five commercial broad-acre cropping and five dairy farms in North-East Victoria, Australia, to compare the performance of DMPP + urea (treatment) against conventional urea (control) fertiliser in mitigating N_2O emissions and increasing crop and pasture yields. Application rate was fixed at the regional industry standard of 46 kg N ha^{-1}, yet timing, number of applications and all other management decisions were left to the judgement of the participating farmers. Emissions of N_2O were highly variable over time and between farms. We recorded emission spikes of up to 250 g N_2O-N ha^{-1} d^{-1}, but 90% of measurements ranged between 1.0–62 g N_2O-N ha^{-1} d^{-1}. Thus, N_2O emissions were dominated by peak fluxes and correlated with soil moisture and the time since fertiliser application. However, there was no significant difference between N_2O emissions from DMPP-treated and control plots in all three seasons. Similarly, crop and pasture yield did not differ significantly between treatment and control. It is likely that the high N application rate was responsible for the poor performance of DMPP under commercial production conditions. Consequently, simply replacing conventional fertiliser with a DMPP-containing product cannot be recommended. Any commercial application of DMPP will need to be accompanied by changes in fertiliser management, of which reducing the N application rate appears most promising.

1. Introduction

Modern agriculture depends on high external inputs of nitrogen (N) to maintain productivity, and inputs are projected to increase further (FAO, 2017). Fertilisation with N in its mineral form as either nitrate (NO_3^-) or ammonium (NH_4^+, commonly applied as urea) has greatly increased food security, but has also been identified as a cause of major environmental problems. Leaching of NO_3^- from soils into waterways is responsible for pollution of groundwater, surface waters and estuaries (Cameron et al., 2013). Gaseous losses of N from agricultural activities in the form of nitrous oxide (N_2O) are the most important source of this greenhouse gas to the atmosphere, and thus contribute significantly to global warming (Denman et al., 2007; Syakila and Kroeze, 2011). Furthermore, volatilisation of ammonia (NH_3) and subsequent atmospheric deposition can cause over-fertilisation of pristine ecosystems and indirect emissions of N_2O (Cameron et al., 2013; Lam et al., 2017).

A number of options exist to reduce losses of N and thus mitigate environmental impacts of N fertilisation, but there is little consensus on the best practice under a commercial farming regime, while maintaining and improving yields. Managerial interventions to reduce losses of N include optimisation of fertiliser application rates and timing, while technological interventions may involve the application of enhanced N fertiliser products, such as nitrification inhibitors (NIs; Chen et al., 2008; Luo et al., 2010). Nitrification inhibitors impair the activity of ammonia-oxidising soil bacteria that catalyse the first and rate-limiting step in the nitrification process, the oxidation of NH_4^+ to nitrite (Ward et al., 2011). Subsequent oxidation of nitrite to NO_3^- is generally not affected. A consequence of nitrification inhibitors is thus a longer residence time of the applied fertiliser in the form of NH_4^+, which readily binds to clay minerals and is thus better protected against

* Corresponding author.
E-mail address: pnauer@unimelb.edu.au (P.A. Nauer).

http://dx.doi.org/10.1016/j.agee.2017.10.022
Received 5 September 2017; Received in revised form 23 October 2017; Accepted 25 October 2017

leaching than the more soluble NO_3^-. Furthermore, inhibiting nitrification leads to reduced emissions of N_2O, a side product in the turnover of mineral N, both under oxic conditions during nitrification, and under anoxic conditions during denitrification (the reduction of NO_3 to N_2; Butterbach-Bahl et al., 2013; Ruser and Schulz, 2015). Nitrification inhibitors therefore reduce losses of N via several pathways, and as a consequence, more of the applied N is plant available (Abalos et al., 2014; Rowlings et al., 2016). Thus, an increase in crop and pasture yield is expected as an indirect outcome.

Among available nitrification inhibitors, 3,4-Dimethylpyrazole phosphate (DMPP; ENTEC©) appears to be a promising candidate for commercial application, as it is effective at low concentrations and thus relatively inexpensive, immobile and has no proven eco-toxicological side effects (Kong et al., 2016; Zerulla et al., 2001). Several recent global meta-analyses on the effect of nitrification inhibitors reported DMPP to be generally effective to reduce agricultural N_2O emissions and to increase yield (Akiyama et al., 2010; Feng et al., 2016; Gilsanz et al., 2016; Yang et al., 2016). Similarly, a number of recent field experiments in Australia discovered that DMPP effectively reduced N_2O emissions up to 75% (Kelly and Ward, 2016; Scheer et al., 2014; Suter et al., 2016a). However, this is contrasted by other Australian field studies that reported DMPP to be ineffective in mitigating N_2O emissions and increasing crop and pasture yield (Dougherty et al., 2016; Koci and Nelson, 2016; Rowlings et al., 2016). Furthermore, DMPP has also been linked to increasing N losses via volatilisation of ammonia (NH_3), which may lead to subsequent deposition and indirect N_2O emissions (Lam et al., 2017). Hence, there is growing uncertainty on the effectiveness of DMPP, particularly on a farm scale. This may relate to the fact that DMPP has mainly been tested in the laboratory, on experimental research stations or, at best, on a separated plot of a commercial farm, but with rigid control of all experimental factors and on a small spatial and short temporal scale. These conditions may not be representative for commercial farming enterprises, where the decisions on when, where and how much fertiliser is to be applied lies with the farmer and depends on a variety of external factors such as weather, market prices, and availability of machinery. Participatory on-farm trials have the advantage of integrating such practical, environmental, commercial and social factors when testing novel farming practices or products (Lawrence et al., 2007). While on-farm trials generally pose additional logistical and experimental challenges (Lawrence et al., 2007; Piepho et al., 2011), they provide a way to put new products or practices to the ultimate “real-life” test, and thus increase acceptance among the farming community (Crofoot, 2010; Guerin and Guerin, 1994). However, to our knowledge, DMPP has not been tested with a participatory on-farm trial under commercial production conditions in Australia and elsewhere.

Hence, our objectives were to investigate the potential benefits of DMPP, i) a reduction of N_2O emissions, and ii) an increase in yield, under typical commercial Australian farming practices for both dry land broad-acre cropping and dry land dairy farms. Farmers retained full control of the management, interventions into the farms’ operational procedures were observational only. This allowed us to assess the “real-life” effectiveness of DMPP-amended fertilizers compared to business-as-usual practices in the important agricultural region of North-East Victoria in Australia.

2. Methods

2.1. Experimental sites

The DMPP fertiliser trial under commercial production conditions ran for three winter growing seasons in 2014–2016. Five broad-acre cropping farms (B) and five dairy pasture farms (D) were selected near Kiewa in North-East Victoria, Australia. The study area typically receives 700–900 mm rain each year (Bureau of Meteorology weather stations no. 082045, 82058 and 72023; Climate Data Online, http://www.bom.gov.au/climate/data/, accessed on 6/6/17). Rainfall is distributed throughout the year, but is typically highest in the winter months (Jun-Aug); this is also the main growing season, as hot and dry summer months (Dec-Feb) are common. Regional practice for non-irrigated pastures is to sow pasture species (dominantly ryegrass, *Lolium perenne* L.) in autumn (Mar-May), with paddock grazing during winter, and harvesting as conserved fodder during spring (Sep-Nov). Typical stocking rates for dairy farms are between 1.8-2.2 head ha^{-1}. For cropping farms, wheat and/or canola crops are sown in autumn, with the main growing period in winter and spring, and harvest in late spring or early summer. Farms in the trial were private commercial enterprises and participated freely with no economic incentives given, except that for participating farmers DMPP was available at urea market prices. Local agronomists liaised between research staff and farmers.

2.2. Experimental design

The on-farm experiment was planned as a multi-environment trial using a half-field design (Piepho et al., 2011). On each of the 10 farms, one field of ~8 ha for dairy and ~80 ha for broad-acre farms was subdivided into two adjacent plots, a “treatment” and a “control” plot of ~4 ha and ~40 ha each. To account for possible plot-scale heterogeneity, treatment and control plots were swapped on each farm from 2014 to 2015, and remained the same in 2016. The treatment plot was fertilised with urea fertiliser amended with the nitrification inhibitor 3,4-dimethylpyrazole phosphate (DMPP), the control plot was treated with urea fertiliser (Urea). Both fertilisers were spread with conventional machinery as part of the farms’ common practice. Decision on the total amount and timing of fertiliser application was left to the judgement of the farmers. Amount of fertiliser spread was 100–200 kg urea ha^{-1} y^{-1} for broad-acre farms and 200–500 kg urea ha^{-1} y^{-1} for dairy farms, spread over 1–5 applications per year, each at 100 kg urea ha^{-1} (46 kg N ha^{-1}). Farmers notified the experimenters in advance or on the day the fertiliser was spread, and subsequent measurements were conducted within 1–3 days after application.

2.3. Nitrous oxide fluxes

Nitrous oxide fluxes were measured generally every 3–7 days for up to 11 times after each fertiliser application using the manual closed chamber method (Hutchinson and Mosier, 1981). Measurement days depended on the application of fertilisers by each farmer (which differed) and the logistics of being able to complete the measurement (not all farms could be reached and measured on the same day due to time restrictions). The chambers consisted of PVC cylinders with a radius of 7.5 cm and 15 cm height, mounted on a permanently installed collar inserted ~2–3 cm into the soil. Each plot had twelve chambers aligned in a straight line. After closing the chamber lid, four 20 mL gas samples per chamber were collected in 15 min intervals with a plastic syringe and injected into 12 mL gas-tight vials. Gas samples of chambers 1–4, 5–8 and 9–12 were combined in the field for each time interval using gas pooling (Arias-Navarro et al., 2013), resulting in three independent flux measurements per plot and sampling date. Concentrations of N_2O were determined using a gas chromatography system equipped with an electron-capture detector (GC-ECD; SRI Instruments, Torrance, CA, USA).

2.4. Soil parameters

For each N_2O flux measurement, soil moisture content was measured adjacent to the chamber using a handheld impedance probe (Theta Probe ML2, Delta-T Devices, Cambridge UK). Soil temperatures at 5 cm depth were measured on two locations next to the experimental plots using automated loggers (HOBO Pro v2, Onset Computer Corporation, Bourne, MA, USA). Soil samples from 0 to 10 cm depth were collected once for each farm and plot in 2014 and 2016, and