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Influence of different nitrogen rates and DMPP nitrification inhibitor on annual N_2O emissions from a subtropical wheat–maize cropping system

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ABSTRACT

Global cereal production will need to increase by 50% to 70% to feed a world population of about 9 billion by 2050. This intensification is forecast to occur mostly in subtropical regions, where warm and humid conditions can promote high N_2O losses from cropped soils. To secure high crop production without exacerbating N_2O emissions, new nitrogen (N) fertiliser management strategies are necessary. This one-year study evaluated the efficacy of a nitrification inhibitor (3,4-dimethylpyrazole phosphate—DMPP) and different N fertiliser rates to reduce N_2O emissions in a wheat–maize rotation in subtropical Australia. Annual N_2O emissions were monitored using a fully automated greenhouse gas measuring system. Four treatments were fertilized with different rates of urea, including a control (40 kg-N ha^{-1} $year^{-1}$), a conventional N fertiliser rate adjusted on estimated residual soil N (120 kg-N ha^{-1} $year^{-1}$), a conventional N fertiliser rate (240 kg-N ha^{-1} $year^{-1}$) and a conventional N fertiliser rate (240 kg-N ha^{-1} $year^{-1}$) with nitrification inhibitor (DMPP) applied at top dressing. The maize season was by far the main contributor to annual N_2O emissions due to the high soil moisture and temperature conditions, as well as the elevated N rates applied. Annual N_2O emissions in the four treatments amounted to 0.49, 0.84, 2.02 and 0.74 kg N_2O–N ha^{-1} $year^{-1}$, respectively, and corresponded to emission factors of 0.29%, 0.39%, 0.69% and 0.16% of total N applied. Halving the annual conventional N fertiliser rate in the adjusted N treatment led to N_2O emissions comparable to the DMPP treatment but extensively penalised maize yield. The application of DMPP produced a significant reduction in N_2O emissions only in the maize season. The use of DMPP with urea at the conventional N rate reduced annual N_2O emissions by more than 60% but did not affect crop yields. The results of this study indicate that: (i) future strategies aimed at securing subtropical cereal production without increasing N_2O emissions should focus on the fertilisation of the summer crop; (ii) adjusting conventional N fertiliser rates on estimated residual soil N is an effective practice to reduce N_2O emissions but can lead to substantial yield losses if the residual soil N is not assessed correctly; (iii) the application of DMPP is a feasible strategy to reduce annual N_2O emissions from sub-tropical wheat–maize rotations. However, at the N rates tested in this study DMPP urea did not increase crop yields, making it impossible to recoup extra costs associated with this fertiliser. The findings of this study will support farmers and policy makers to define effective fertilisation strategies to reduce N_2O emissions from subtropical cereal cropping systems while maintaining high crop productivity. More research is needed to assess the use of DMPP urea in terms of reducing conventional N fertiliser rates and subsequently enable a decrease of fertilisation costs and a further abatement of fertiliser-induced N_2O emissions.

1. Introduction

Agricultural soils play a fundamental role in the increase of nitrous oxide (N_2O) in the atmosphere, contributing approximately to 50% of the global anthropogenic N_2O emissions (IPCC, 2001). The environmental relevance of increasing concentrations of N_2O in the

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atmosphere resides both in the elevated global warming potential of N_2O (296 CO_2-eq over a 100 year time horizon) and its contribution to the depletion of the ozone layer in the stratosphere (Ravishankara et al., 2009).

The increase of N_2O emissions from agricultural soils is directly connected to the increment in worldwide nitrogen (N) fertiliser use (Bouwman, 1990; Kroeze et al., 1999). About 60% of worldwide N fertiliser is presently used to crop cereals (Ladha et al., 2005). However, more fertiliser N is expected to be used in cereal cropping systems to meet the grain demand of 9 billion people in 2050 (Ladha et al., 2005; UNFPA, 2011). This intensification of cereal production is forecast to occur mostly in subtropical regions (IPCC, 2007), where warm and humid conditions can promote high N_2O losses from fertilised soils (Bouwman et al., 2002). New fertiliser management strategies are necessary to secure future subtropical cereal production without increasing N fertiliser use and therefore N_2O emissions.

Conventional N fertiliser rates used in subtropical cereal systems are defined without taking into account the N left in the soil profile by the previous crop (called residual soil N). Many studies have observed that the proportion of N_2O losses as a function of N fertiliser rates rise in nonlinear patterns when soil N amounts exceed plant need (Van Groenigen et al., 2010; Grace et al., 2011). The application of excessive amounts of fertiliser N rates can be avoided by taking into account site-specific conditions affecting residual soil N, such as crop management and crop rotations (Dobermann and Cassman, 2002; Pampolino et al., 2007). Conventional N fertiliser rates can be therefore adjusted to actual crop needs taking into account the amount of N left by the previous crop. As a result, our first hypothesis in this study was that by reducing conventional N rates after accounting for residual soil N, N_2O emissions can be abated without significantly penalizing yields.

The second hypothesis of this research was that N_2O emissions generated by the application of conventional fertiliser rates can be reduced by nitrification inhibitors. The application of nitrification inhibitors to urea-based fertilisers has been shown to decrease N_2O emissions both directly, via slowing the nitrification rates and, indirectly, by reducing the amount of NO_3^- available to denitrifying bacteria (Linzmeier et al., 2001; Hatch et al., 2005; Suter et al., 2010). Among nitrification inhibitors, 3,4-dimethylpyrazole phosphate (DMPP) has been reported by many authors as the most efficient in slowing nitrification and reducing N_2O losses (Weiske et al., 2001a,b; Liu et al., 2013).

However, the vast majority of data on N_2O emissions from fertilised cereal systems refer to temperate regions or laboratory conditions and the efficacy of these fertilisation strategies in reducing N_2O emissions in subtropical environments still remains unknown. The efficiency of DMPP in reducing N_2O emissions from urea can be strongly influenced by site-specific conditions such as soil temperature and soil water content (Chen et al., 2010; Menéndez et al., 2012).

The overall aims of this study were therefore to: (i) determine whether a reduction in conventional N fertiliser rates according to local crop history can reduce N_2O emissions without affecting crop yields; (ii) evaluate the effects of DMPP urea applied at conventional rates on N_2O emissions and crop yields; (iii) improve the understanding of environmental factors influencing N_2O emissions from subtropical cereal cropping systems.

N_2O emissions from a wheat–maize crop rotation in subtropical Queensland (Australia) were monitored for one year using a fully automated greenhouse gas measuring system. Both crops were fertilised with different rates of urea, including a control, a conventional N fertiliser rate adjusted according to estimated residual soil N, a conventional N fertiliser rate and the conventional rate with DMPP urea.

This is the first study to report annual N_2O emissions from a cereal cropping system under subtropical conditions, the results of which will help defining fertilisation strategies aimed at reducing N_2O emissions from subtropical cereal cropping systems while maintaining high crop productivity.

2. Materials and methods

2.1. Study site

Annual N_2O fluxes were measured from wheat (July to November 2011) in rotation with maize (December 2011 to June 2012) at the J. Bjelke Petersen Research Station of the Department of Agriculture, Fisheries and Forestry (DAFF). The research site is located in Taabinga (26°58′16,8″ Latitude South, 151°82′85.3″ Longitude East, altitude 441 m a.s.l), near Kingaroy, in the southern inland Burnett region of southeast Queensland, Australia. The climate is classified as subtropical, with warm, humid summers and mild winters, with frequent frosts occurring between June and August. Daily mean maximum and minimum temperatures are 20.1 and 4.0 °C in winter and 29.6 and 16.5 °C in summer, respectively. Mean annual precipitation is 776.2 mm and varies from a minimum of 28.6 mm in August to a maximum of 114.1 mm in January (Australian Bureau of Meteorology). The soil is classified as a Brown Ferrosol (Australian Soil Classification, Isbell (2002)), is slowly permeable, with a high clay content (50–65% clay) in 1.4 m of effective rooting zone and a water holding capacity of 100 mm. Physical and chemical soil properties are listed in Table 1.

2.2. Experimental design

The field trial was a randomised complete block design with three replicates per treatment. Each plot measured 13 m in length × 6 m in width, with crop rows oriented NNW-SSE. To avoid edge effects, each plot was separated by a buffer of 6 m and 0.8 m along the width and length, respectively.

The field was cropped to wheat (*Triticum aestivum* L., cultivar Hartog) from 8 June to 27 November 2011 and to maize (*Zea mays* L., cultivar 32P55) from 20 November 2011 to 20 June 2012. Local farmer practice was followed and during the early stages of crop development the entire field trial was sprinkler irrigated with surface stored dam water. All treatments received the same amount of water simultaneously at each event. As reported in Table 2, throughout the duration of the experiment four fertilisation treatments were tested:

- Control test (CNT): no N fertiliser applied to wheat, urea (prills) applied at rate of 40 kg N ha^{-1} to maize to guarantee a minimum crop establishment.
- Conventional N fertiliser rate adjusted according to estimated residual soil N (CONV-ADJ): urea (prills) applied at rates of 20 and 100 kg N ha^{-1} to wheat and maize, respectively. Seasonal

Table 1
Main soil physical and chemical properties of the experimental site at Kingaroy research station, Queensland, Australia.

Soil property	0–10 cm	10–20 cm	20–30 cm
Carbon (g kg^{-1})	14.67 ± 1.36	14.07 ± 0.55	10.82 ± 2.41
Nitrogen (g kg^{-1})	0.92 ± 0.09	0.86 ± 0.06	0.57 ± 0.04
pH (H_2O)	5.50 ± 0.08	5.57 ± 0.03	5.66 ± 0.05
Texture (USDA)	Clay	Clay	Clay
CEC (meq+/100 g)	14.14 ± 0.10	14.71 ± 0.45	15.54 ± 2.29
Bulk density (g cm^{-3})	1.23	1.40	1.36
Clay (%)	50	55	60
Silt (%)	17	14	10
Sand (%)	33	31	30