Effect of reduced fertiliser rates in combination with a nitrification inhibitor (DMPP) on soil nitrous oxide emissions and yield from an intensive vegetable production system in sub-tropical Australia

Clemens Scheer[1], Mary Firrell[2], Peter Deuter[2], David Rowlings[1], Ian Porter[3], Peter Grace[1]

[1]Institute for Future Environments, Queensland University of Technology, Brisbane, QLD 4000, Australia, clemens.scheer@qut.edu.au
[2]Department of Agriculture, Fisheries and Forestry (Queensland), Gatton Research Station, QLD 4343, Australia
[3]School of Life Sciences, LaTrobe University, Bundoora, Vic 3083,Australia

Abstract
Vegetable production systems are characterised by intensive production with high inputs of nitrogen fertiliser and irrigation water. Consequently, high emissions of nitrous oxide have been reported. The use of nitrification inhibitors (NI) offers an effective method to reduce N_2O emissions, whilst maintaining yield and increasing nitrogen use efficiency. However, only limited data are currently available on the use of NI in vegetable cropping systems. A field experiment was conducted to investigate the effect of the nitrification inhibitor 3,4-Dimethylpyrazol phosphate (DMPP) in combination with reduced N fertilizer application rates on N_2O emissions and yield from a typical vegetable rotation in sub-tropical Australia. Annual N_2O emissions ranged from 0.59 to 1.37 kgN/ha for the different fertiliser treatments. A 40% reduced fertilizer rate combined with DMPP reduced N_2O emissions by more than half but achieved a comparable yield to the standard grower's practice in two out of three crops. We conclude that DMPP shows a great potential for reducing N_2O emissions from vegetable systems. However, further research is required to understand under what conditions reduced N rates of DMPP coated fertiliser are applicable and to determine the long-term effect of such a fertiliser regime over extended cropping cycles.

Key Words
Nitrification inhibitor, 3,4-Dimethylpyrazol phosphate (DMPP), Entec, Nitrous oxide (N_2O),

Introduction

Nitrous oxide (N_2O) is an important greenhouse gas due to a high global warming potential (298 times that of CO_2) and is also the principal ozone-depleting substance in the 21st century (IPCC, 2013). Agricultural soils play a key role in the increase of N_2O in the atmosphere, contributing to 70% of all anthropogenic N_2O emissions. These emissions are predicted to double by 2050, largely due to increased fertilizer and manure N applications to croplands (Davidson and Kanter, 2014). Vegetable systems are often characterised by high inputs of N fertiliser. Consequently, high emissions of N_2O (up to 240 kg N_2O-N $ha^{-1}yr^{-1}$) have been reported from heavily fertilised sub-tropical vegetable production systems in China (Jia *et al.*, 2012), and it is estimated that globally 45 Mt CO_2–eq. per year are emitted from synthetic fertiliser used in vegetable production systems (Rashti *et al.*, 2015). Moreover, it has been shown that vegetable crop residues incorporated into the soil after harvest can be decomposed rapidly and release mineral N and easily available C resulting in high long lasting (2-6 weeks) fluxes of N_2O (Scheer *et al.*, 2014). However, so far there is only limited data on N_2O emissions from vegetable production based on detailed field measurements.

Over recent years, the use of nitrification inhibitors (NI), in combination with ammonium based and ammonium producing (urea) fertilisers, has been promoted as an effective method to reduce N_2O emissions from fertilised agricultural fields, whilst increasing yield and nitrogen use efficiency. However, to date there are only limited data on the effect of NI on N_2O emissions and yield in vegetable production systems. Up to now only two studies investigated the effect of DMPP coated fertiliser on N_2O emissions in intensive vegetable production systems. While one study found a 50% reduction in N_2O emissions over one year (Pfab *et al.*, 2012), the other study found no significant effect of DMPP on N_2O emissions over a broccoli-fallow period (Scheer *et al.*, 2014). In addition, there have been inconsistent results on the effect of DMPP on yield and quality of vegetable crops, with some studies showing that DMPP may increase yield (Pasda *et al.*, 2001), while others did not find any agronomic advantage with the use of DMPP (Pfab *et al.*, 2012; Scheer *et al.*, 2014). Consequently, the aims of this study were to quantify the effect of the use of DMPP coated fertiliser in combination with reduced N fertilizer application rates on soil N_2O emissions and yield from an intensive vegetable production system in sub-tropical Australia

Methods

Site description

The study was conducted over an entire year from September 2014 to September 2015 in the Lockyer Valley, Queensland, Australia (latitude 27°32'56"S, longitude 152°19'39"E; 100m a.s.l.). The Lockyer Valley is a major vegetable producing region in south-east Queensland, characterized by a humid subtropical climate, with a humid summer and mild to cool winters. Annual average temperature is 20 °C with an average annual maximum of 27 °C and minimum of 13 °C. Summer rainfall accounts for nearly 60% of the total annual rainfall of 787 mm. The alluvial soil is classified as a Black Vertisol (FAO, 1998) which is characterized by high shrink-swell potential due to its high montmorillonite clay content (>50%).

Field management and experimental design
The experiment was conducted using four fertiliser treatments in three replications arranged in a randomized complete block design. Each experimental plot was 1.5 m wide x 10 m in length, with 2 rows per plot for the sweet corn and broccoli crops and 3 rows per plot for the lettuce crop. A 1 m wide buffer zone was included between plots. The fertiliser treatments were:

i. Standard grower practice (SGP) – i.e. standard grower practice of Nitrophoska® and urea fertilizer N application rates.
ii. 100% DMPP – addition of DMPP coated fertiliser (ENTTEC Nitrophoska® and ENTTEC® urea) with SGP N application rates.
iii. 80% DMPP – addition of DMPP coated fertiliser (ENTTEC Nitrophoska® and ENTTEC® urea) with a 20% reduced N application rate compared to SGP.
iv. 60% DMPP – addition of DMPP coated fertiliser (ENTTEC Nitrophoska® and ENTTEC® urea) with a 40% reduced N application rate compared to SGP.

Vegetable crops were established using standard commercial practice. SGP treatments received a total of 340 kg-N/ha over one year. Fertilizer was applied by hand ensuring even application over each plot and incorporated using a rotary hoe. A timeline of the experiment is shown in Table 1.

Table 1. Timeline of crop management of the annual vegetable crop rotation.

Date	Management
Sweet Corn	
23 Sept. 2014	Basal fertilizer application (78 kg-N ha^{-1} Nitrophoska™)
24 Sept. 2014	Planting using seed
22 Oct. 2014	Fertilizer side dressing (42 kg-N ha^{-1} Urea)
8 Dec. 2014	Harvest
23 Dec. 2014	Incorporation of crop residues (rotary hoe)
Broccoli	
16 Feb. 2015	Basal fertilizer application (78kg-N ha^{-1} Nitrophoska™)
17 Feb. 2015	Transplanting using container grown seedlings
25 Mar. 2015	Fertilizer side dressing (42 kg-N ha^{-1} Urea)
16, 21, 27 Apr. 2015	Harvest
12 May 2015	Incorporation of crop residues (rotary hoe)
Lettuce	
9 Jun. 2015	Basal fertilizer application (50 kg-N ha^{-1} Nitrophoska™)
10 Jun. 2015	Transplanting using container grown seedlings
21 Jul. 2015	Fertilizer side dressing (50 kg-N ha^{-1} Urea)
25 Aug. 2015	Harvest
1 Sept. 2015	Incorporation of crop residues (rotary hoe)

N_2O flux measurement and data analysis
Measurements were taken from every plot using a fully automated measuring system. Fluxes of N_2O were calculated from the slope of the linear increase or decrease over the 4 concentrations measured over the closure time. For further details please refer to Scheer et al. (2014). Analysis of variance (ANOVA) was performed to determine whether the fertilizer treatment had significant influence on N_2O emissions and crop yields. The Bonferroni *post hoc* test was used to compare cumulative N_2O emissions, grain yields and total N uptake across treatments. Statistical analysis was undertaken using SPSS 16.0 (SPSS Inc., USA).

Results

N_2O emissions
The majority of N_2O fluxes occurred in response to fertilizer application and rainfall/irrigation events, as well as post-harvest after the incorporation of crop residues into the soil (Figure 1). There were two significant N_2O emission peaks in the SGP treatment over the sweet corn cropping period in late October and early December, after periods of high rainfall, while only small emissions were observed in all DMPP treatments. Incorporation of the sweet corn crop residues in early December was followed by frequent rainfall events in late December and early January, which resulted in a four week period of elevated N_2O fluxes in all treatments, with

significantly higher emissions in those treatments with added DMPP. The basal fertilizer application and rotary hoe bed preparation at planting of the broccoli resulted in a small emission peak in all treatments. The fertilizer side dressing was followed by several rainfall events in late March and early April, with sustained N_2O fluxes over one week and significantly higher emissions in the SGP treatment. Incorporation of the broccoli crop residues again caused elevated emissions in all treatments. Transplanting of the lettuce in combination with the basal fertilizer application and rotary hoe incorporation resulted in another sustained emission peak with significantly higher emissions in the SGP treatment.

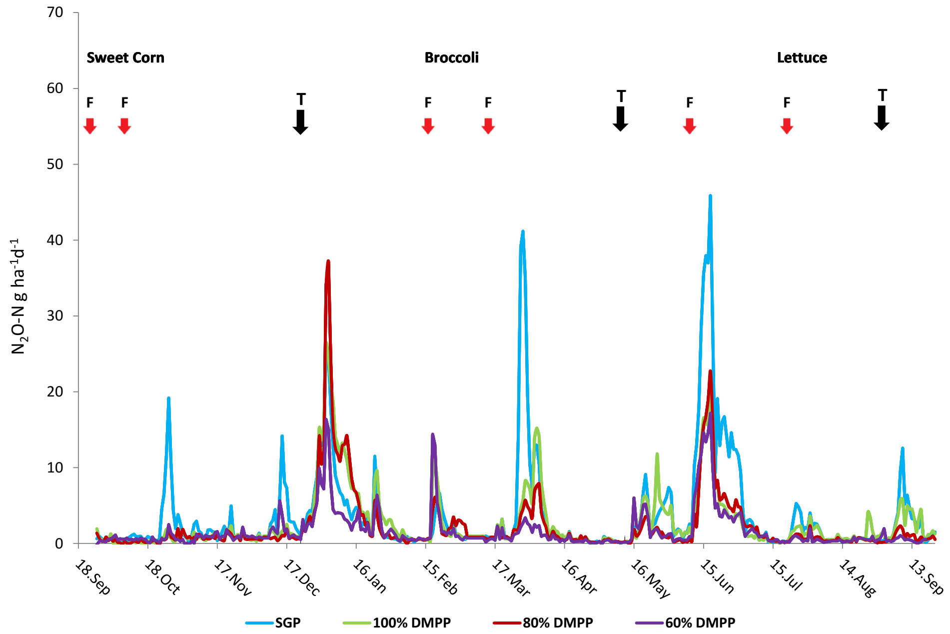

Figure 1. N_2O fluxes for the different fertilizer treatments over the one year vegetable crop rotation. Red arrows indicate the time of fertilizer application. Black arrows indicate rotary hoe incorporation of crop residues.

Cumulative N_2O emissions were estimated to be 1.37, 0.98, 0.80 and 0.59 kg N_2O-N ha^{-1} yr^{-1} for the SGP, 100%DMPP, 80%DMPP and 60%DMPP treatments, respectively (Table 2). The use of DMPP reduced annual emissions by 29% compared to the SGP treatment, while DMPP in combination with reduced N fertilizer rates reduced annual emissions further (i.e. 42% and 57% in the 80%DMPP and 60%DMPP treatments, respectively).

Table 2: Average and annual N_2O fluxes.

	Average N_2O Flux [g-N $ha^{-1}day^{-1}$]	Annual N_2O Flux [kg-N ha^{-1} $year^{-1}$]
SGP	3.75	1.37
100% DMPP	2.68	0.98
80% DMPP	2.19	0.80
60% DMPP	1.62	0.59
Se	0.27	0.10
LSD **(p<0.05)**	1.23	0.45

Crop Yield

Total sweet corn yield ranged from 10.9 to 11.7 t ha^{-1}, total broccoli yield ranged from 9.4 to 11.7 t ha^{-1} and total lettuce yield from 61.9 to 68.8 t ha^{-1} across the different fertilizer treatments (Table 3). There was no significant effect of fertilizer rate or DMPP application on sweet corn and lettuce yield. However we did find a significant effect of reduced rates of DMPP fertilizer on broccoli yield, where there was an 11% and 20% reduction in yield compared to the SGP treatment in the 80%DMPP and 60%DMPP treatments, respectively.

Discussion

Overall, N_2O emissions were low compared to emissions reported for other vegetable cropping systems where often extraordinarily high emissions are found (Liu *et al.*, 2013). This confirms previous results and demonstrates that the Black Vertisol soil has a limited N_2O emission potential, most likely due to a limited availability of labile carbon and the alkaline soil pH (Scheer *et al.*, 2014). N_2O emissions were mainly influenced by rainfall/irrigation events following N fertilizer application over the vegetable cropping period. However, extended periods of N_2O emissions also occurred post-harvest following the rotary hoe incorporation of crop residues into the soil. This highlights again that the management of crop residues is a crucial driver for soil N_2O emissions in vegetable production system (Scheer *et al.*, 2014). DMPP showed a great potential to reduce N_2O emissions in this system, in particular when it is combined with reduced fertilizer rates. The use of DMPP with the standard grower's fertilizer practice reduced N_2O emissions by 29% compared to the SGP treatment, and a reduced fertilizer rate combined with DMPP reduced N_2O emissions by more than half. This supports results from other studies in vegetable production systems, where a reduction of up to 50% has been reported (Pfab *et al.*, 2012).

Table 3: Total yield [t ha^{-1}] for the three vegetable crops.

Treatment	Sweet Corn	Broccoli	Lettuce
SGP	10.9	11.7	68.8
100% DMPP	11.7	11.5	65.8
80% DMPP	11.3	10.4	68.0
60% DMPP	11.3	9.4	61.9
SE	0.20	0.39	1.47
LSD	-	1.05	-

However, the application of reduced fertilizer rates also increases the risk of yield penalties for the farmer. Whilst yield potential could be maintained with reduced DMPP, N rates for the sweet corn and the lettuce crops, there was an 11% and 20% reduction in broccoli yield compared to the SGP treatment in the 80% DMPP and 60% DMPP treatments, respectively. We assume that broccoli, being a much shallower rooted crop, has not been able to forage as efficiently for soil nutrients as lettuce and especially sweet corn, which have much more extensive root systems.

Conclusion

The use of DMPP shows a great potential in reducing N_2O emissions from this vegetable system while sustaining high yields. However, to be economically attractive for farmers, a reduced rate of fertilizer needs to be applied to offset the higher cost associated with DMPP fertilizer. This was the case for the sweet corn and the lettuce crops, but not for broccoli. This highlights that DMPP fertilizer rates need to be considered carefully and demonstrates that more research is needed to identify optimised strategies for DMPP fertilizer application in vegetable systems. Moreover, long term studies are required to determine if reduced rates of DMPP fertiliser can sustain high yields over extended cropping cycles or if this fertilizer regime mines N from the soil organic matter pool.

References

Davidson EA, Kanter D, (2014). Inventories and scenarios of nitrous oxide emissions. Environ. Res. Lett. 9, 105012.

FAO (1998). World reference base for soil resources. World soil resources reports 84. Food and Agriculture Organization of the United Nations.

IPCC (2013). Fifth Assessment Report. Climate Change 2013: The Physical Science Basis. . Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Jia J, Sun L, Kong X, Yan X, Xiong Z, (2012). Annual N_2O and CH_4 emissions from intensively managed vegetable fields in Nanjing, China. Soil Sci. Plant Nutr. 58, 91-103.

Liu Q, Qin Y, Zou J, Guo Y, Gao Z, (2013). Annual nitrous oxide emissions from open-air and greenhouse vegetable cropping systems in China. Plant Soil, 370 (1-2) 223-233.

Pasda G, Hähndel R, Zerulla W, (2001). The new nitrification inhibitor DMPP (ENTEC®)—Effects on yield and quality of agricultural and horticultural crops. In Plant Nutrition. Springer Netherlands, 758-759.

Pfab H, Palmer I, Buegger F, Fiedler S, Müller T, Ruser R, (2012). Influence of a nitrification inhibitor and of placed N-fertilization on N_2O fluxes from a vegetable cropped loamy soil. Agric. Ecosyst. Environ. 150, 91-101.

Rashti MR, Wang W, Moody P, Chen C, Ghadiri H, (2015). Fertiliser-induced nitrous oxide emissions from vegetable production in the world and the regulating factors: A review. Atmos. Environ. 112, 225-233.

Scheer C, Rowlings DW, Firrel M, Deute, P, Morris S, Grace PR, (2014). Impact of nitrification inhibitor (DMPP) on soil nitrous oxide emissions from an intensive broccoli production system in sub-tropical Australia. Soil Biol. Biochem. 77, 243-251.