Low nitrous oxides emissions from Australian processing tomato crops – a win for the environment, our health and farm productivity

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Abstract

Nitrous oxide is a potent greenhouse gas. It can also increase ultraviolet radiation transmission and incidence of skin cancers by depleting the ozone layer, and is a waste of applied nitrogen fertiliser. Nitrous oxide emissions from four commercial farms growing processing tomatoes (*Solanum lycopersicum*) in the Rochester-Echuca-Boort area of Victoria, Australia were monitored during the 2014–15 growing season. Low crop nitrous oxide emissions were measured, ranging from 0.23 to 1.51 kg N_2O-N ha^{-1} across the four farms. The emissions intensity of the four farms was very low, ranging from 0.0014 to 0.011 kg N_2O-N tonne $fruit^{-1}$. The greatest risk period for nitrous oxide emissions was during plant establishment due to the reliance on sub-surface drip and the need to apply excess water to wet the soil surface. Inadvertently, the application of metham sodium appears responsible for reducing average nitrous oxide emissions over the high-risk plant establishment period. In 2015, emissions after planting were 4.5 times greater when no metham sodium was applied. The low measured nitrous oxide emissions meant that the Cool Farm Tool, the main industry reporting tool, produced nitrous oxide emission estimates that were up to 11 times higher than those measured during the 2014–15 season. When compared to other produce, the Australian processing tomato sector is well placed with very low emissions intensities.

INTRODUCTION

Nitrogen fertiliser and irrigation management not only drive processing tomato yields but also play a major role in determining the environmental impacts of crop production. Nitrous oxide emissions – which are a potent greenhouse gas, increase ultraviolet radiation and skin cancer by depleting the ozone layer, and waste applied nitrogen fertilisers – can be significant from tomato and other vegetable crops (Kennedy et al. 2013; Liu et al. 2013). The use of sub-surface drip irrigation combined with nitrogen fertigation can substantially reduce nitrous oxide emissions with reductions of over 70% compared to furrow irrigation reported (Kennedy et al. 2013).

Nitrous oxide emissions from processing tomatoes are being compared in different production areas through the use of industry reporting tools such as the Cool Farm Tool (Hillier 2011). Changes in crop production practices may not be reflected in these reporting tools or generic default emission factors (Smith et al. 2001).

Emission intensity is increasingly being used to compare agricultural practices and the greenhouse emission profiles of a range of produce. The benefits of yield-scaling to produce emissions intensity is that it takes into account both the need for food production and environmental impacts such as in this case, contributing to global warming. Emission intensity can vary considerably between crops with values ranging from 1.5 kg N2O-N tonne fruit-1 for apples; 2.3 kg N2O-N tonne fruit-1 for cherries (Swarts et al. 2016); while the emissions intensity of the major grain crops of wheat and maize were reported at 45.2 and 50.4 kg N_2O-N tonne grain^{-1} (Linquist et al. 2012).

This study monitored nitrous oxide emissions across four commercial farms growing processing tomatoes in Victoria. Very low nitrous oxide emissions were measured compared to those estimated by models or other intensively managed vegetable crops. The practices which produce these low emissions are highlighted.

SITES AND METHODS

Sample farms and agronomy

Four commercial processing tomato (*Solanum lycopersicum*) farms in the Rochester-Echuca-Boort area of Victoria were monitored during the 2014–15 growing season. The four farms varied in soil properties (Table 1). The soil organic matter of farm 1 was 22–56% higher in the topsoil, compared to the other farms. Farm 1 was a new block with this the first tomato crop grown; farms 2–4 had previously grown tomatoes. Farm 1 had the highest residual soil nitrate-nitrogen levels prior to fertiliser application and applied the greatest proportion of fertiliser nitrogen as a pre-plant basal fertiliser; 57% compared with 21–32% at the other three farms (Table 2).

Cultivation across the four farms involved disc, power harrow and deep ripping prior to bed forming. All farms applied metham sodium (192 L ha^{-1}) for 15–27 days before planting. Irrigation was applied using only sub-surface drip, with a single drip line buried 25cm along the middle of the bed.

Across the four farms planting dates were 30th, 6th 14th and 20th of October 2014, respectively. The processing tomato crop was established using seedling transplants (farms 1–3) or direct seeding (farm 4) of a single row, directly above the single sub-surface drip line. Immediately following planting, irrigation was applied through the sub-surface drip system until water reached the soil surface. During the remainder of the growing season drip irrigation was applied on demand with 43–79% of the nitrogen applied as fertigation (Table 2). There were no significant in-season rainfall events (>30 mm) during 2014–15.

The crops were mechanically harvested and yield (tonnes ha^{-1}) measured at each of the four farms on the 5/3/2015, 12/2/2015, 11/2/2015, and 11/3/2015, respectively.

Table 1. Differences in soil characteristics across the four farms. (n.d. not determined)

	OM	pH	Texture	Bulk density	Olsen P	NO_3-N	CEC	K	Ca	Mg
	(%)	($CaCl_2$)		(g cm^{-3})	(ppm)	(ppm)	(Meq 100g^{-1})			
Farm	*Depth 0-15 cm*									
1	6.1	5.2	Sandy loam	1.1	32	73	11.0	1.1	5.6	4.1
2	3.9	6.6	Loam	1.0	20	32	21.2	1.4	12.7	6.2
3	5.0	7.7	Loam	0.9	14	20	55.0	1.3	43.2	8.8

4	4.0	7.6	Clay	0.9	27	17	30.3	1.1	17.0	9.3
	Depth 15-30 cm									
1	4.8	5.2	Sandy loam	n.d.	23	39	8.8	0.6	4.3	3.6
2	3.6	6.4	Loam	n.d.	6	19	20.2	0.9	10.9	7.0
3	4.6	7.7	Loam	n.d.	11	21	56.1	1.3	43.2	9.3
4	3.9	7.5	Clay	n.d.	32	19	30.3	0.9	16.9	8.8

Table 2. Differences between the four commercial farms in residual soil NO_3-N prior to fertilising, and nitrogen fertiliser applied prior to planting (basal), or during the growing season (fertigation).

	Nitrogen supply (kg ha^{-1})			
	Soil NO_3-N	Fertiliser-N		
Farm		Basal	Fertigation	Total
1	121	126	96	222
2	47	36	134	170
3	26	72	152	224
4	21	49	110	159

Nitrous oxide measurement

Eight static chambers (installed volume of 7.3L; four on the shoulder of the bed and four in the centre of the bed directly above the sub-surface drip line) on each farm were used to monitor nitrous oxide emissions. Sampling for nitrous oxide focused on cultivation and basal fertiliser application, planting and fertigation events. At each sampling date, gas samples were taken at 0, 30 and 45 minutes after the chamber was sealed. Gas samples were transferred into 10 ml Exotainers and sent to the laboratory for nitrous oxide analysis using gas chromatography. Sample nitrous oxide concentrations were then used to calculate the flux from the soil (g N_2O-N ha^{-1} day^{-1}). The measured nitrous oxide emissions were used to calculate crop emissions on an area basis (kg N_2O-N ha^{-1}) and as an emission intensity (g N_2O-N tonne $fruit^{-1}$).

Nitrous oxide estimation from models

The project used the Cool Farm Tool (Hillier et al 2011) and the Intergovernmental Panel on Climate Change (IPCC, Smith 2001) default emission factor to estimate nitrous oxide emissions. Based on these estimates, crop emissions on an area basis (kg N_2O-N ha^{-1}) and as emission intensity (kg N_2O-N tonne $fruit^{-1}$) were calculated.

RESULTS

Measured crop nitrous oxide emissions – variations across farms

Measured crop nitrous oxide emissions were low across farms 2, 3 and 4, ranging from 0.23 to 0.45 kg N_2O-N ha^{-1} (Figure 1). By contrast, crop emissions from farm 1 were 3–7 times higher at 1.51 kg N_2O-N ha^{-1}. The higher emissions at farm 1 were mainly due to a spike in daily emissions immediately following planting and wetting up of the soil, where soil volumetric water content (VWC) exceeded 50%. Emissions jumped from less than 1.0 prior to planting, to a peak of 78 g N_2O-N ha^{-1} day^{-1} after planting (Figure 2). Other farms only recorded small increases in emissions associated with the watering up at planting despite having similar soil VWC.

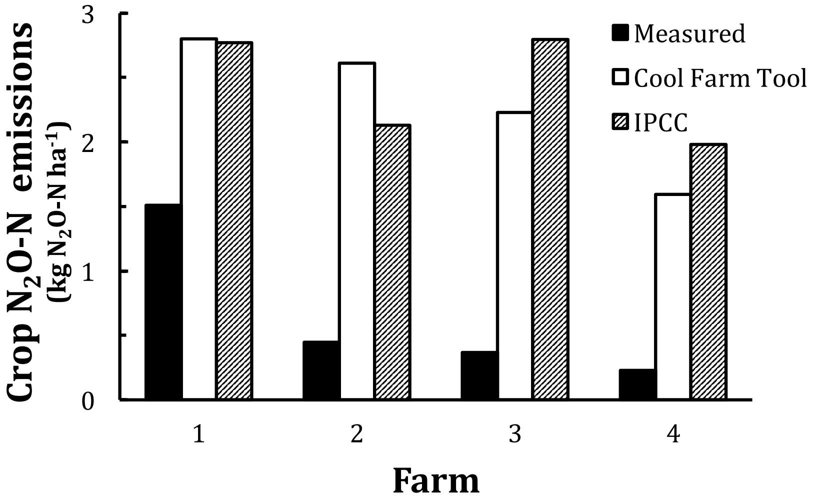

Figure 1. Processing tomato crop nitrous oxide emissions measured or estimated by models (Cool Farm Tool) or IPCC defaults, for the 2014–15 growing season.

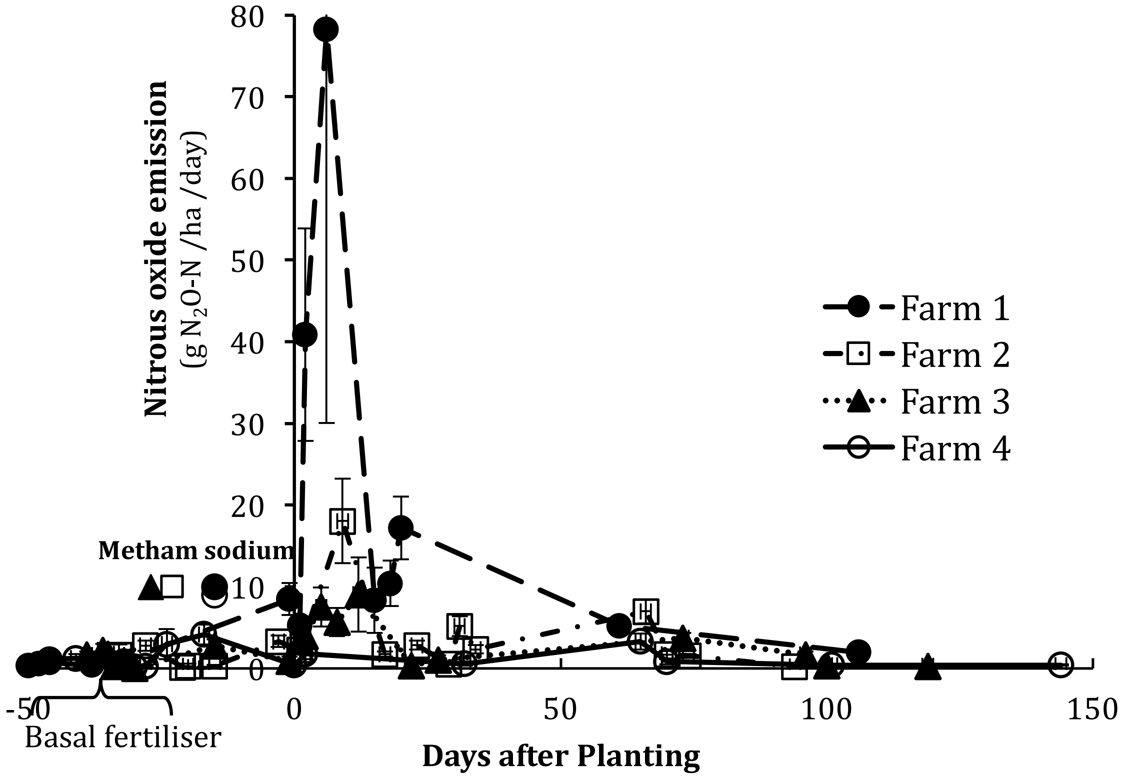

Figure 2. Daily nitrous oxide emissions from the four processing tomato growing farms in Victoria, Australia normalised based on planting date. Metham sodium was applied 15–27 days before planting as indicated by individual symbols for the four farms. The timing of basal nitrogen fertiliser application and cultivation is indicated by the parenthesis.

The tomato fruit yield for the four farms was 139.9, 109.8, 92.0 and 167.0 t ha^{-1}, respectively. The yield variations resulted in a greater range of emission intensity than crop nitrous oxide emission. Farm 4 produced the least emission per tonne of fruit with an emission intensity of 0.001 kg N_2O-N tonne $fruit^{-1}$ (Figure 3). The emission intensity doubled to 0.002 and 0.002 kg N_2O-N tonne $fruit^{-1}$ for farms 2 and 3, respectively. But farm 1 had the largest emission intensity with a value of 0.011 kg N_2O-N tonne $fruit^{-1}$.

Nitrous oxide emission – measured vs modelled

The modelled nitrous oxide emission values were considerably higher than the measured values for both the Cool Farm Tool and IPCC methods (Figure 1). The models overestimated crop emission by 10–12 times for farms 2–4 and 0.8 times for farm 1. Neither the Cool Farm Tool nor IPCC default values produced the measured variation in emissions across farms. For example, the Cool Farm Tool's estimated emissions varied by 75% between the highest and lowest farm, while the measured emissions varied by 830%. Similarly, the Cool Farm Tool and IPCC overestimated the emission intensity (Figure 3).

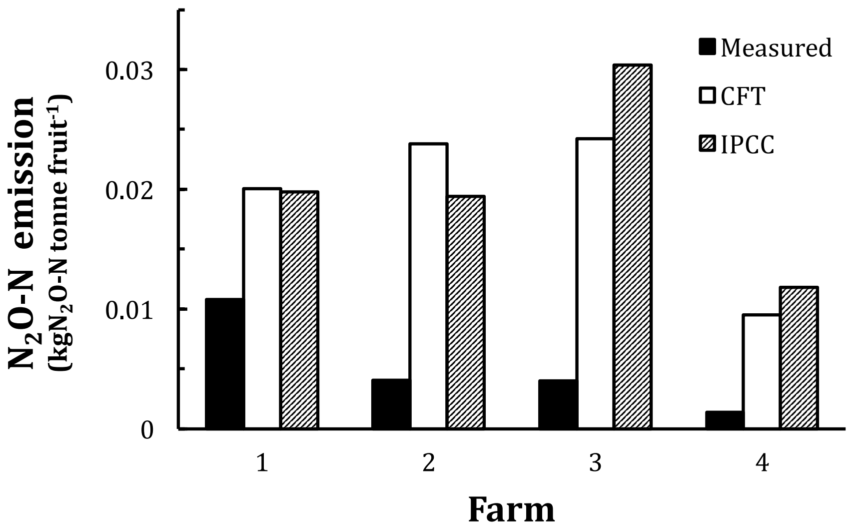

Figure 3. Comparison of nitrous oxide emission intensity (g N_2O-N tonne $fruit^{-1}$) estimated by models (Cool Farm Tool; CFT) or IPCC, or measured during the 2014–15 season.

DISCUSSION

Environmental, health and farm productivity benefits of low crop nitrous oxide emissions

The measured low nitrous oxide emissions from the processing tomato crop are a win for the environment, our health and for farm productivity (Figures 1 & 2). A summary of global data on reported N_2O emissions from vegetable fields reported a mean average emission of 57.8 g N_2O-N ha^{-1} day^{-1}(Liu et al 2013), substantially higher than the daily average of 1.3 – 10.8 g N_2O-N ha^{-1} day^{-1} measured across the four farms.

The Australian industry adoption of sub-surface drip irrigation and fertigation is a prime driver of the low nitrous oxide emissions monitored in this study. Comparisons of sub-surface drip and furrow irrigation in California showed a more than 70% decrease in crop nitrous oxide emissions under sub-surface drip, with results similar to those measured in this study (Kennedy et al. 2013). Higher emissions were measured at farm 1 (Figure 1), clearly identifying planting time as the greatest risk of nitrous oxide emissions (Figure 2). This risk period and the potential impact of metham sodium will be discussed further after we consider the benefits of low crop nitrous oxide emissions from the Australian processing tomato industry.

Low nitrous oxide emissions are a win for the environment due to the potent greenhouse impact of nitrous oxide. Nitrous oxide stays in the atmosphere for more than 100 years, with one tonne of nitrous oxide equivalent to 298 tonnes of carbon dioxide when it comes to global warming potential (Grace and Barton 2014). By reducing nitrous oxide emissions growers are permanently reducing their greenhouse impact.

Low nitrous oxide emissions are a win for our health. Nitrous oxide is an ozone destroyer, more important than CFCs and unregulated by the Montreal Protocol (Ravishankara et al. 2009). Skin cancer is already a disease of epidemic proportions in Australia, which has the highest incidence in the world of the most lethal form of skin cancer. It is estimated that for every 1 per cent decrease in ozone, there could be a 4–6% increase in skin cancers (Beder, 1992).

Reducing nitrous oxide emissions also improves farm productivity. Nitrous oxide emissions are nitrogen fertiliser lost. While the direct amount of nitrogen lost via nitrous oxide is small, about 0.2 to 1.5 kgN/ha across the four farms, nitrous oxide is an indicator of overall denitrification loss, which typically averages 40 times that of nitrous oxide. During the 2014–15 season, nitrogen fertiliser lost to the atmosphere would have ranged from 8 – 60 kgN ha^{-1}, or 5–27% of the nitrogen fertiliser applied.

The emissions intensity of the four processing tomato farms was very low, ranging from 0.0014 to 0.018 kg N_2O-N tonne $fruit^{-1}$ (Figure 3). This is substantially lower than for other fresh or grain crops. With sustainable intensification considered an important approach to the challenge of achieving food security (Garnett et al. 2013), emission-intensity measures will become a more important way of comparing agricultural production systems and practices. In this respect, the Australian processing tomato is well placed with very low emissions intensities.

Planting – the greatest risk period for nitrous oxide emissions

Planting has been identified as the greatest risk period for nitrous oxide emissions from processing tomatoes grown across the four farms (Figure 2). The use of sub-surface drip to irrigate at planting results in saturated soils creating conditions conducive to nitrous oxide emissions. However, only at one farm were significant nitrous oxide emissions measured during this period (Figure 2). We attribute this to the higher soil organic matter at farm 1 combined with the highest pre-fertiliser soil nitrate level and the highest rate of basal nitrogen fertiliser being applied. Nitrous oxide emissions are a biological process mediated by soil microbes when soil oxygen becomes limiting. The high soil organic matter would be expected to support a more active population of soil microbes with a greater potential for nitrous oxide emissions.

Nitrogen management is the key to reducing the risk of nitrous oxide emissions during planting. There are limited options to reduce the irrigation rates when only sub-surface drip irrigation is used at planting. Reducing the soil nitrate levels at planting is the most practical method for reducing the risk nitrous oxide emissions. This can be achieved by reducing the basal fertiliser rates, and increasing the amount of nitrogen applied via fertigation. These practices were followed at farms 2–4 and may have contributed to the low nitrous oxide emissions at planting observed at these farms (Table 2, Figure 2). However, they do not fully explain why no increases in nitrous oxide emissions were observed.

Metham sodium was applied at all farms prior to planting. Metham sodium is a powerful fumigant that impacts on the soil microbial community and function for up to 18 weeks after application (Macalady et al 1997). As nitrous oxide emissions are produced by soil microbes under anaerobic conditions it is possible that the application of metham sodium prior to planting has reduced emissions at planting. This was confirmed in 2015 where nitrous emissions were 4.5 time greater when no metham sodium was applied (average daily emissions of 29.2 c.f. 6.5 g N_2O-N ha^{-1} day^{-1} when metham sodium was applied). Thus, inadvertently, the application of metham sodium appears responsible for reducing nitrous oxide emissions over the high-risk plant establishment period.

Processing tomato industry reporting

The Australian processing tomato industry is part of a global industry and provides comprehensive reports on its environmental performance. The Cool Farm Tool is used by the industry to estimate greenhouse emissions from on- and off-farm activities in producing tomato products. We found that the Cool Farm Tool and IPCC default values both substantially overestimated crop nitrous oxide emissions and emission intensity compared to the measured emissions during 2014-15 (Figures 1 & 3). The Cool Farm Tool produced estimates that were up to 11 times higher than measured, while the IPCC estimates were up 14 times higher. Furthermore, neither the Cool Farm Tool nor the IPCC accounted for the differences between farms observed in measured nitrous oxide emissions or the emission intensity.

CONCLUSION

The Australian processing tomato industry adoption of sub-surface drip irrigation and fertigation is a prime driver of the low nitrous oxide emissions monitored in this study. In addition, metham sodium applied prior to planting appears to be playing an important role in reducing emission during the high-risk planting period when excess irrigation is applied to ensure plant establishment. These factors combine to produce very low crop nitrous oxide emissions and emission intensity. We found that the Cool Farm Tool overestimated emissions by up to 11 times higher than measured, while the IPCC estimates were up 14 times higher. When compared to other produce the Australian processing tomato industry is well placed with very low emissions intensities.

ACKNOWLEDGEMENTS

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