Nitrous oxide emissions from soils in Australian sugarcane production systems

Peter Thorburn[A], Jody Biggs[A] and Merv Probert[A]

[A]CSIRO Sustainable Ecosystems and Sustainable Agriculture Flagship, 306 Carmody Rd, St Lucia, QLD, Australia,
Email peter.thorburn@csiro.au

Abstract

Use of nitrogen fertiliser is a major cause for increased emissions of nitrous oxide (N_2O) from soils, which are the biggest source of greenhouse gas emission from sugarcane production. To reduce greenhouse gas emissions from sugarcane production, and increase the crop's attractiveness as a sustainable biofuel, we will need a better understanding of N_2O emissions from soils and how they can be managed. To investigate both the management and consequences of management of these emissions, we simulated whole-of-crop N_2O emissions over a range of environments and management practices in Australia. Predictions of N_2O emissions were consistent with the few measurements made previously, and support conclusions from these measurements that N_2O emissions from sugarcane soils are greater than expected from experience in other crops. We also predict that emissions in other sugarcane areas will be as high, or higher than those measured. The ability to mechanistically simulate emissions of similar magnitude to those measured give added confidence in the measurements. We provide an example of the degree to which higher nitrogen fertiliser prices might reduce both N_2O emissions and sugarcane production, and show that the economic value of the mitigated emissions may be substantially lower than the value of lost productivity.

Key Words

Denitrification, greenhouse gas, mitigation, APSIM, irrigation, trash.

Introduction

Use of nitrogen (N) fertiliser is a major cause of increased emissions of N_2O, a potent greenhouse gas, from soils. Commercial sugarcane production requires substantial applications of N fertilisers, which may result in N_2O emissions from soils being the biggest greenhouse gas emitted from sugarcane production (Thorburn *et al.* 2009). Yet there are relatively few measurements of N_2O emissions from sugarcane, and most of those have been made in Australia (e.g. Weier *et al.* 1996, 1998; Weier 1999; Denmead *et al.* 2008; Wang *et al.* 2008; Macdonald *et al.* 2009). Emissions are higher than expected compared with other cropping systems and N fertiliser use (Galbally *et al.* 2005). While emissions are of general concern because of their high impact on global warming, they are of particular concern for sugarcane production because of the wide interest in the crop for biofuel production. Additional information on N_2O emissions from sugarcane soils will help identify management practices to reduce them, and the likely consequence of implementing these practices. Simulation models are increasingly being employed, in addition to experiments, to gain information on N_2O emissions from cropping systems (e.g. Del Grosso *et al.* 2009). APSIM is a farming systems simulator (Keating *et al.* 2003) with a well developed capacity to simulate N dynamics in sugarcane systems (Thorburn *et al.* 2005). Recently, the denitrification processes in APSIM have been tested and the capability added for partitioning denitrified N into the different gasses produced by the process, N_2O and dinitrogen (Thorburn *et al.* 2010a). Thus, APSIM is now a useful tool for exploring potential N_2O emissions from sugarcane production systems in areas and/or for issues where measurements are unavailable. In this paper, we use APSIM to investigate N_2O emissions from a range of conditions found in sugarcane production in Australia, both in regions where emissions have been previously measured and where there is no information. We also explore some options for reducing N_2O emissions and the economic impacts they may have.

Methods

Contrasting sugarcane production systems were analysed using long term (40-60 years) simulations to investigate how N_2O emissions from soils varied (full details are given by Thorburn *et al.* 2010a). The systems were based on soils, climate and crop management information from previous studies of sugarcane production in four regions. These spanned a wide range of environments, including the super-humid tropics (Tully; ~17.9S, 145.9E), dry tropics (Burdekin River Irrigation Area; ~19.8S, 147.2E), humid tropics (Mackay, two soils; ~21.2S, 149.0E) and dry sub-tropics (Maryborough; ~25.5S, 152.7E). N_2O emissions have previously been measured in the Mackay region, at Eton (Weier *et al.* 1998) and Te Kowai (Denmead *et al.* 2008; Macdonald *et al.* 2009), allowing verification of the predicted emissions.

A range of management practices and soils were represented in the simulations. Irrigation management varied, with sugarcane fully irrigated in the Burdekin simulations, grown under supplementary irrigation in Maryborough simulations and not irrigated in the other environments. Simulations for the two soils in Mackay each had two different crop residue managements (retention and removal). The amount of N applied in the simulations reflected common practice in the regions, ranging from over 200 kg/ha (averaged across all crops and fallows) in the Burdekin region to less than 130 kg/ha in the Tully and Maryborough regions (Figure 1). Soils ranged from clays in the Burdekin and the Eton site in Mackay, to sandy-clay-loams at the Te Kowai site in Mackay. Average cane yields in the simulations ranged from 74 t/ha (averaged across all crops), at Maryborough, to 80-84 t/ha for the loamy soils at Tully and Mackay (Te Kowai), to 87-91 t/ha in the clay soils of Mackay (Eton) and the Burdekin.

For the Te Kowai site in Mackay, cane yield, N_2O emissions and the profitability of sugarcane production were also predicted for a wide range of N application rates (35-200 kg/ha), keeping all other management factors the same as in the previous simulations. Profitability was represented by the partial gross margin (PGM) to farmers, calculated from the income from sugarcane (assuming a sugar price of AU\$400/t and CCS of 13.5) less the cost of N fertiliser. The N application rate corresponding to the highest PGM was identified over a range of N prices to explore the sensitivity of N_2O emissions, which are a function of N rate, to N price, assuming N application rates were those that gave the highest profitability.

Results and discussion
Magnitude of emissions
Nitrous oxide emissions from soils were equivalent to 2-5% of N fertiliser applied (Figure 1) in the simulations. The simulated emissions from the Mackay-TeKowai site were consistent with independent measurements of emissions (Denmead *et al.* 2008; Macdonald *et al.* 2009). The results also support the conclusions from these and other experiments (Weier *et al.* 1996, 1998; Weier 1999; Allen *et al.* 2008; Wang *et al.* 2008) that N_2O emissions from soils in Australian sugarcane crops are substantially greater than expected for the level of N fertiliser use and experience in other crops (Galbally *et al.* 2005). The ability to mechanistically simulate emissions of similar magnitude to those measured give added confidence in the measurements. Additionally, we provide the first estimates of emissions for fully irrigated production (Burdekin) and partly irrigated production (Maryborough), and rainfed production in the wet tropics (Tully), and predict them to be similar or higher than emissions in other regions. While very high emissions (~20% N fertiliser) have been measured from sugarcane growing in highly acidic soils with shallow water tables (Denmead *et al.* 2008; Wang *et al.* 2008), these areas are relatively small in Australia and are unlikely to represent the common situation.
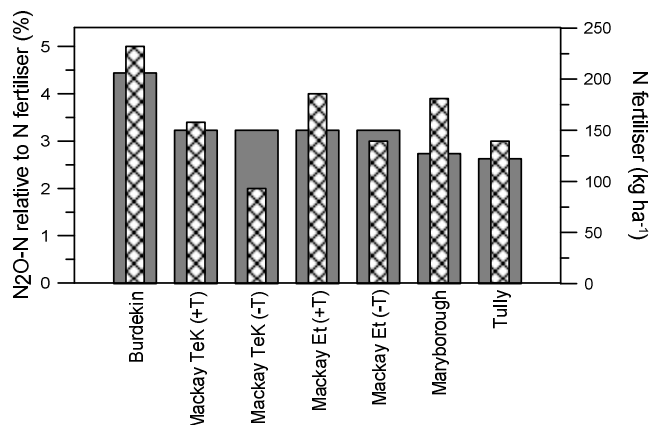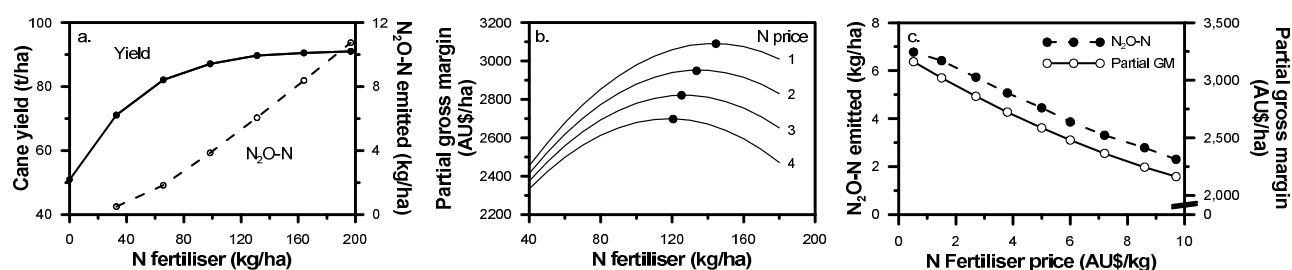

Figure 1. Simulated, long-term average N_2O-N emissions from soils (hatched bars) and N fertiliser applications (grey bars) at five sites. For Mackay, sites were at Te Kowai (TeK) and Eton (Et) and either had crop residues retained (+T) or removed (-T) in the simulations.

If our predictions prove generally correct, global warming potential of world-wide sugarcane production may be equivalent to 29-48 Mt CO_2-e year[-1]. This is 2-3 % of the global warming potential attributed to N_2O emissions from all fertilised croplands (Stehfest and Bouwman 2006). We suggest that reducing N_2O from soils growing sugarcane is likely to be a higher priority than may have been previously thought for increasing the sustainability of sugarcane production, both in Australia and globally.

The variations in emissions between regions were consistent with the processes known to drive N_2O emissions. At the Mackay sites for example, predicted emissions were higher from the clay soil at Eton than the more loamy soil at Te Kowai. Also, retaining crop residues on these soils increased simulated denitrification and N_2O emissions, as expected from experimental results (Weier *et al.* 1998). Emissions were simulated to be high at the Burdekin site, reflecting the heavy textured soils combined with the fully irrigated nature of cane production in Burdekin River Irrigation Area. Our results therefore indicate that the cause of the high N_2O emissions from sugarcane is the relatively warm and moist climate and the availability of carbon in the soils.

Managing emissions

Reducing N fertiliser applications will reduce N_2O emissions from soils (Stehfest and Bouwman 2006). But what might the cost be, in terms of lost production, relative to the benefit? Improved N recommendations have shown there is considerable scope for reducing N rates in Australian sugarcane production without significantly reducing productivity (Thorburn *et al.* 2010b). Thus at Te Kowai for example (Figure 2a), reducing N application from 170 kg/ha (the recent average in that region) to 120 kg/ha would reduce N_2O emissions by ~40% with little or no loss of production and a consequent increase in profitability.

Figure 2. Simulated, long-term average response of (a) cane yields and soil N_2O-N emissions to increasing application of N fertiliser, (b) maximum partial gross margins at different N fertiliser prices, and (c) the change in N_2O emissions and maximum partial gross margin with increasing N fertiliser price (assuming N fertiliser is applied at the rate corresponding to the maximum partial gross margin shown in b) for the Te Kowai site.

However, N applications may also be reduced if the price of N fertiliser increases, a likely event if emissions trading schemes are introduced. As N fertiliser prices increase, maximum profitability occurs at lower N application rates (Figure 2b). So farmers **may** respond to price increases by reducing N applications, which would result in lower N_2O emissions. However, with increased N price, not only is the N rate at which maximum profitability reduced, the maximum profit itself also decreases. Thus, higher N prices could result in both lower N_2O emissions and lower farm profitability if farmers respond by reducing N applications. In the simulations for Te Kowai, the trade off between N_2O emissions and farm profitability can be illustrated for varying N prices by taking the N rate at which maximum PGM occurs (i.e. the dots on the curves in Figure 2b) and calculating the corresponding N_2O emissions and PGM values over a range of N prices (Figure 2c). In this example, N_2O emissions decrease by ~0.46 kg N_2O-N/ha for each unit (i.e. AU$1) increase in N price. If the price of carbon is AU$20/t CO_2-e the value of the reduced N_2O emissions is ~AU$4.25. The corresponding decrease in PGM is ~AU$98 per unit increase in N price, or more than 20 times the value of N_2O emissions. The economic impact of increased N prices will be even greater if price increases are such that they drive N applications low enough so that cane yields and sucrose concentrations are reduced. In this situation, the reduced cane and sugar supply would potentially reduce mill profitability. This analysis illustrates the point that decreases in N fertiliser application rates, below recommended rates, as a response to higher N prices could have substantial negative net economic effects.

Nitrous oxide emissions from soils are enhanced by high concentrations of nitrate and carbon in the soils and anaerobic soil conditions. Thus, as well as reducing N fertiliser applications, other management practices affect N_2O emissions. In our simulations, as expected, the highest relative emissions occurred in the two irrigated production systems, Burdekin and Maryborough (Figure 1). In irrigated production systems, minimising water logging following irrigation will help reduce N_2O emissions. Also as expected, retaining crop residues also increased emissions (Figure 1). Given the advantages of this widely-adopted practice in Australian sugarcane production, other methods to reduce emissions will need to be employed. Practices such as splitting N fertiliser applications may help (Weier 1999; Allen *et al.* 2008), as might slow release fertilisers or nitrification inhibitors (Wang *et al.* 2008), although the benefits of these practices have not been consistent.

References

Allen D, Kingston G, Rennenberg H, Dalal R, Schmidt S (2008) Nitrous oxide emissions from sugarcane soils as influenced by waterlogging and split N fertiliser application. *Proceedings of the Australian Society of Sugar Cane Technologists* **30**, 95-104.

Del Grosso SJ, Ojima DS, Parton WJ, Stehfest E, Heistemann M, DeAngelo B, Rose S (2009) Global scale DAYCENT model analysis of greenhouse gas emissions and mitigation strategies for cropped soils. *Global Planetary Change* **67**, 44–50.

Denmead OT, Macdonald BCT, Naylor T, Wang W, Salter B, White I, Wilson S, Griffith DWT, Moody PW (2008) Whole-of-season greenhouse gas emissions from Australian sugarcane soils. *Proceedings of the Australian Society of Sugar Cane Technologists* **30**, 105-114.

Galbally I, Meyer M, Bentley S, Weeks I, *et al.* (2005) A study of environmental and management drivers of non-CO_2 greenhouse gas emissions in Australian agro-ecosystems. *Environmental Science* **2**, 133–142.

Keating BA, Carberry PS, Hammer GL, Probert ME (2003) An overview of APSIM, a model designed for farming systems simulation. *European Journal of Agronomy* **18**, 267–288.

Macdonald BCT, Denmead OT, White I, Naylor T, Salter B, Wilson S, Griffith DWT (2009) Emissions of nitrogen gases from sugarcane soils. *Proceedings of the Australian Society of Sugar Cane Technologists* **31**, 85-92.

Stehfest E, Bouwman L (2006) N_2O and NO emission from agricultural fields and soils under natural vegetation: summarizing available measurement data and modeling of global annual emissions. *Nutrient Cycling in Agroecosystems* **74**, 207–228.

Thorburn PJ, Biggs JS, Collins K, Probert ME (2010a) Nitrous oxide emissions from Australian sugarcane production systems – are they greater than from other cropping systems? *Agriculture Ecosystems and Environment* **136**, 343–350.

Thorburn PJ, Meier EA, Probert ME (2005) Modelling nitrogen dynamics in sugarcane systems: Recent advances and applications. *Field Crops Research* **92**, 337-352.

Thorburn P, O'Connell D, Grant T (2009) Enhancing the assessment of biofuels feedstock production through more realistic representation of farming systems. In 'Proceedings of Conference on Integrated Assessment of Agriculture and Sustainable Development: Setting the Agenda for Science and Policy, Egmond aan Zee, The Netherlands, 10-12 March 2009'. (Eds MK Van Ittersum, J Wolf , HH Van Laar) pp. 388-389. (Wageningen University and Research Centre: Wageningen).

Thorburn PJ, Webster AJ, Biggs JS, Biggs IM (2010b) A new way to determine nitrogen fertiliser requirements of sugarcane crops to meet global environmental challenges. *Plant and Soil* (in press).

Wang WJ, Moody PW, Reeves SH, Salter B, Dalal RC (2008) Nitrous oxide emissions from sugarcane soils: Effects of urea forms and application rate. *Proceedings of the Australian Society of Sugar Cane Technologists* **30**, 87-94.

Weier KL (1999) N_2O and CH_4 emission and CH_4 consumption in a sugarcane soil after variation in nitrogen and water application. *Soil Biology and Biochemistry* **31**, 1931-1941.

Weier KL, McEwan CW, Vallis I, Catchpoole VR, Myers RJK (1996) Potential for biological denitrification of fertiliser nitrogen in sugarcane soils. Australian Journal of Agricultural Research **47**, 67-79.

Weier KL, Rolston DE, Thorburn PJ (1998) The potential for N losses via denitrification beneath a green cane trash blanket. *Proceedings of the Australian Society of Sugar Cane Technologists* **20**, 169-175.