Potential for summer active grasses to minimise gaseous soil N losses

M.E. McNee[1], K.C. Flower[1,2], L. Nazaries[3], S. Manalil[2], B.K. Singh[3]

[1] Western Australian No-Till Farmers Association, PO Box 1091, Northam WA 6401, matthew.mcnee@wantfa.com.au
[2] School of Plant Biology and Institute of Agriculture, The University of Western Australia, Crawley WA 6009
[3] Hawkesbury Institute for the Environment, The University of Western Sydney, Richmond NSW 2753

Abstract
A replicated field experiment commenced in October 2013 at Meenaar, Western Australia, on a sandy duplex soil to compare the effects of summer chemical fallow with millet crops on soil nitrous oxide (N_2O) emissions. A closed chamber technique was used where the soil within and outside the chamber was wet uniformly with the equivalent of 40mm of rainfall over a $0.7m^2$ area to initiate the anaerobic conditions that result in N_2O production. The net N_2O flux over the period of one hour was 4.4g N_2O-N ha^{-1} h^{-1} in the chemical fallow treatment, which was 40-42% higher than the rate observed in the millet treatments. The results indicate the potential for summer cover crops to reduce N_2O emissions in the short term. Further research is required to compare the total loss of N_2O in cropping rotations that replace summer fallow with crops.

Key words
Cover crop, denitrification, climate change, greenhouse gas

Introduction
Summer active grasses like *Panicum miliaceum* (cv. white French millet) dry out the soil over summer and may help to alleviate water logging, and deep drainage of soil water and nitrogen (Robertson et al., 2005). The growth of summer grasses might also minimize soil N losses that occur after summer rainfall as a consequence of nitrous oxide emissions. It has been proposed that drought tolerant grass cover crops will scavenge for available water and nitrogen in the soil over summer, thereby limiting the available energy source for bacteria that produce nitrous oxide gas (Dalal et al., 2003). This paper presents results for nitrous oxide emissions measured after treatments of 1) summer fallow with chemical weed control, 2) millet crops grown for 16 weeks and 3) millet crops grown for 21 weeks. The experiment is part of a four-year study, near Meckering in the central cropping region of south Western Australia, that is assessing the potential benefits of summer crops included in continuous wheat rotations.

Materials and methods
Site, soil and treatments
A four-year cropping experiment commenced in 2013 at Meenaar (116°86´E, 31°62´S) in the central cropping zone of south-east Western Australia. The soil surface was sandy with 59g/kg clay, 12.7g/kg total carbon, 9g/kg organic carbon, 1g/kg total nitrogen, 13mg/kg phosphorus (Colwell) in the top 10cm of soil. Most of the available mineral nitrogen (NH_4^+, NO_3^-) for plants was located in that layer. The clay content of the subsoil was generally higher than the sandy top, with between 59 g/kg clay and 159 g/kg clay from 10-30cm. The treatments commenced with the sowing of the summer crops on 25 October 2013, after a wheat crop was cut for hay and the site was sprayed with glyphosate (2l/ha Roundup Ultramax®) to kill weeds. The treatments were,

1. chemical fallow (CF) with weeds controlled with herbicides as required;
2. millet cover crop (MCC) killed early with herbicides after 16 weeks growth (5 weeks prior to soil N_2O sampling);
3. millet crop (MC) killed late by cutting and removing plants after 21 weeks growth (at the time when soil N_2O was sampled).

Each treatment was replicated four times in the experiment. Millet was sown with no-tillage knife-points on 0.22m row spacing with a seeding rate of 8kg/ha. Superphosphate fertiliser was also applied at a rate of 100kg/ha at seeding. The soil surface was wet at sowing (7.31% v/v, 0-12cm) following above average spring rainfall.

Field and laboratory activities

A closed chamber technique was used to compare the net flux of nitrous oxide (N_2O) in fallow and millet crop treatments on 26 March 2014. Two replicate gas sampling chambers were installed onto the soil surface, to a depth of 5cm, in each treatment plot the day prior the commencement of sampling. The mean height of each chamber above the soil surface was measured so that the volume of the chambers could be calculated. Any plants (i.e. millet or weeds) that were growing within the chamber area were removed by cutting them at their base, near to the soil surface, prior to the sampling. Nitrous oxide gas was sampled from the treatment plots in replicates 1 and 2 in the morning after 10a.m. and 3 and 4 were done before 3p.m. in the afternoon. The soil within and around each chamber was wet with 20 L of water uniformly applied over 0.7m^2 (equivalent to ~28mm rainfall). Sampling commenced immediately after the chamber lids were fitted (time zero) and then at 20 minute intervals until the lids were removed after the final sample (time 60 minutes) i.e. the chamber deployment period was 1 hour. The temperature inside each chamber was recorded over the sampling period using an iButton® logger suspended from the chamber lid. The extracted gases (25ml) were immediately transferred from a syringe into gas-evacuated 10ml glass vials (Agilent, USA), that had been sealed with aluminium crimp caps and butyl septa. Nitrous oxide concentration was estimated on a gas chromatograph (GC) system (7890-0505, Agilent Technologies, USA) with an electron-capture detector (µECD). Four soil cores (0-10cm) were collected with a hand auger from the wet area around each chamber and bulked together. The soil was dried in an oven at 45ºC for 48 hours and the amount of ammonium (NH_4^+) and nitrate nitrogen (NO_3^-) in each soil sample was tested at a commercial laboratory.

Estimation of net N_2O flux

Nitrous oxide flux was estimated as the change in concentration inside the chamber headspace over the chamber deployment time (i.e. 1 hour) using linear (LR) (Matthias et al., 1980) and quadratic (Q) models (Wagner et al., 1997). The models chosen were those that best suited the nature of the data points of a particular series (a "best-fit" approach) since linear models tend to underestimate the real fluxes, but quadratic models are less sensitive. Underestimation of the real fluxes can also occur when there are differences in soil properties in the treatments. Differences in soil air-filled porosity can effect gas exchange at the soil-atmosphere interface after chamber deployment (Liebig et al., 2012; Venterea, 2010; Venterea et al., 2009). The theoretical flux underestimation (TFU) was calculated in each treatment using the methods described by Venterea et al. (2010) to ensure that mean treatment fluxes were not artifacts of the imposed treatments.

Statistics

Differences in net N_2O flux in the treatments were calculated with a generalised linear mixed model (Genstat11th edition). The fixed parameter 'replicate' was included in the model to account for random effects. The log-normal distribution was used since the sample data was positively skewed (Venterea et al., 2009). Means were considered significantly different at $p \leq 0.05$.

Results

Treatment fluxes

Millet crop biomass was low (<500kg/ha) as a result of there being no in-crop rainfall in one of the driest summers for south-eastern WA on record. Nitrate nitrogen in the chemical fallow (NH_4^+, 0-10cm) was 13.2kg/ha which was higher than 9.4kg/ha and 6.6kg/ha after the millet cover crop and millet crop respectively (l.s.d. = 3.2, p=0.008). There was no difference in ammonium nitrogen (NO_3^-, 0-10cm) in the treatments. The net flux of nitrous oxide (Figure 1) in the chemical fallow was 4.4g N_2O-N ha/h compared to ~2.6g N_2O-N ha/h in both of the millet treatments (p=0.038). There was no effect of killing the millet after 16 or 21 weeks.

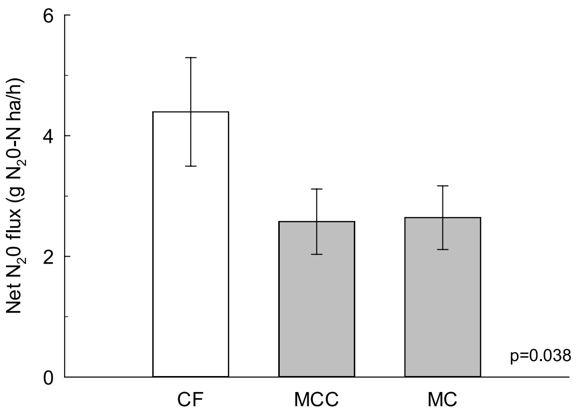

Figure 1. Comparison of the net nitrous oxide flux observed in late March in a chemical fallow (CF) a millet cover crop (MCC) killed early 5 weeks prior to sampling and a millet crop killed late on the day of sampling.

Discussion

The mechanism(s) driving N2O emissions

In a very dry summer, the crops used soil water and acquired available nitrogen for growth. It follows that there was less nitrogen in the soil surface compared to the chemical fallow where weeds were killed as early as possible with herbicides to conserve water and nitrogen. There was 40-42% higher nitrous oxide flux observed in the summer chemical fallow treatments than the millet plots. In this dry year, with low millet biomass production, the duration of millet crop growth had no effect on nitrous oxide flux. Lower flux rates with summer crops might be explained by less soil N assimilated by denitrifying bacteria in anaerobic soil conditions. However, other drivers of soil N_2O emissions like the availability of carbon in the soil also need to be considered. Sowing summer crops does incorporate some crop residues into the soil, potentially increasing residue decomposition rates compared to fallow. The presence of summer crop roots may also influence the abundance and activity of soil micro and macro flora.

A fit for cropping systems?

To confirm a net benefit from cropping systems that include summer crops, N losses (including other N loss pathways) would need to be quantified over longer periods of time e.g. subsequent N losses through leaching and into the atmosphere through the decomposition of the summer crop residues. Improvements in soil fertility over the longer term, from the addition of summer crop residues each year, might result in higher N_2O emissions after summer rainfall. The justifications for farmers to undertake changes in management should be aligned with their farm production e.g. N_2O emissions in relation to crop productivity (Van Groenigen et al., 2010). For example, summer crops could help to minimise emissions after rainfall and also serve as beneficial break/cover crops that improve the yields of winter crops in continuous cereal rotations (Krupinsky et al., 2002; Krupinsky et al., 2007).

A fit for the agricultural landscape?

The total emissions of nitrous oxide that have been measured from cropped soil in WA are low comparative to other cropping regions with higher rainfall in southern and eastern Australia (Barton et al., 2008; Barton et al., 2013). However, there are regions like the southern cropping zone, closer to the coast, of WA that are more likely to experience frequent and high summer rainfall.

Conclusions

Replacing fallowed land over summer with cover crops shows promise as a method to minimise soil N losses through nitrous oxide emissions. The extent of the benefits will depend on the frequency and amount of summer rainfall. Further work is required to quantify N losses over a longer period to confirm a benefit for cropping systems and climate change mitigation.

Acknowledgements

This project is funded by the Australian Government Department of Agriculture, Carbon Farming Futures - Action on the Ground Program.

References

Barton, L., Kiese, R., Gatter, D., Butterbach-Bahl, K., Buck, R., Hinz, C., and Murphy, D. V. (2008). Nitrous oxide emissions from a cropped soil in a semi-arid climate. *Global Change Biology* **14**, 177-192.

Barton, L., Murphy, D. V., and Butterbach-Bahl, K. (2013). Influence of crop rotation and liming on greenhouse gas emissions from a semi-arid soil. *Agriculture, Ecosystems & Environment* **167**, 23-32.

Dalal, R. C., Wang, W., Robertson, G. P., and Parton, W. J. (2003). Nitrous oxide emission from Australian agricultural lands and mitigation options: a review. *Soil Research* **41**, 165-195.

Krupinsky, J. M., Bailey, K. L., McMullen, M. P., Gossen, B. D., and Turkington, T. K. (2002). Managing Plant Disease Risk in Diversified Cropping Systems. *Agronomy Journal* **94**, 198-209.

Krupinsky, J. M., Tanaka, D. L., Merrill, S. D., Liebig, M. A., Lares, M. T., and Hanson, J. D. (2007). Crop Sequence Effects on Leaf Spot Diseases of No-Till Spring Wheat. *Agronomy Journal* **99**, 912-920.

Liebig, M. A., Franzluebbers, A. J., and Follett, R. F., eds. (2012). "Managing Agricultural Greenhouse Gases. Co-ordinated Agricultural Research through GRACEnet to Address our Changing Climate," pp. 1-547. Academic Press, Elsevier Inc., London, United Kingdom.

Matthias, A. D., Blackmer, A. M., and Bremner, J. M. (1980). A Simple Chamber Technique for Field Measurement of Emissions of Nitrous Oxide from Soils. *Journal of Environmental Quality* **9**, 251-256.

Robertson, M. J., Gaydon, D., Hall, D. J. M., Hills, A., and Penny, S. (2005). Production risks and water use benefits of summer crop production on the south coast of Western Australia. *Australian Journal of Agricultural Research* **56**, 597-612.

Van Groenigen, J. W., Velthof, G. L., Oenema, O., Van Groenigen, K. J., and Van Kessel, C. (2010). Towards an agronomic assessment of N2O emissions: a case study for arable crops. European Journal of Soil Science **61**, 903-913.

Venterea, R. T. (2010). Simplified Method for Quantifying Theoretical Underestimation of Chamber-Based Trace Gas Fluxes J. Environ. *Qual*. **39**, 126-135.

Venterea, R. T., Spokas, K. A., and Baker, J. M. (2009). Accuracy and Precision Analysis of Chamber-Based Nitrous Oxide Gas Flux Estimates Soil Sci. *Soc. Am. J.* **73**, 1087-1093.

Wagner, S. W., Reicosky, D. C., and Alessi, R. S. (1997). Regression Models for Calculating Gas Fluxes Measured with a Closed Chamber. *Agronomy Journal* **89**, 279-284.