The influence of increasing organic matter content on N_2O emissions

Lynne Macdonald[1], Mark Farrell[1] and Jeff Baldock[1]

[1] CSIRO Agriculture, PMB2, Glen Osmond, SA 5064, Australia (lynne.macdonald@csiro.au)

Abstract
The carbon (C) and nitrogen (N) cycles in soil are intrinsically linked. Recently, and with particular reference to increased awareness of climatic change, there has been focus on increasing sequestration of C in agricultural soils as a potential greenhouse gas mitigation strategy. However, increased C content in soils often also leads to an increased rate of both C and N cycling. In the context of C accounting and defining the net greenhouse gas benefits of sequestering atmospheric CO_2-C in soil, it is important to understand the potential implications of building soil C on the flux of N_2O generated by N cycling processes (Zaehle *et al.* 2011).

Key Words
Nitrous oxide, carbon sequestration, greenhouse gas emissions

Introduction

Cycles of C and N in soil are intrinsically linked. Both C and N are integral to the molecular composition of soil organic matter and the ratio of their contents is constrained. Cleveland and Liptzin (2007) reported mean ± standard deviation of 12.2 ± 0.4 for the gravimetric C/N ratio across 146 non-agricultural soils (untilled, unfertilized and free of intensive agriculture). Kirkby *et al.* (2011) provided mean gravimetric C/N ratios of 11.2 for 527 agricultural and non-agricultural international soils and 11.8 for 59 Australian agricultural soils. The implication of these findings is that, as soil organic matter content increases, soil organic N content must also increase.

Development and implementation of agricultural practices capable of increasing soil organic matter contents are currently being encouraged to improve and maintain soil quality and to mitigate emissions of greenhouse gases. For the purposes of greenhouse gas mitigation and carbon accounting policy, the net benefit of any accumulations (sequestration) of soil organic C in the form of organic matter must also consider the implications on emissions of other greenhouse gases. As organic matter accumulates, increased N contents may lead to enhanced emissions of nitrous oxide (N_2O) mediated by the biological processes of nitrification and denitrification (Figure 1). Understanding the magnitude of N_2O emission brought about by increasing soil organic matter content is therefore important to defining the net greenhouse gas mitigation associated with sequestering atmospheric CO_2-C in soil in the form of organic C.

The objectives of the work completed were to quantify the chemical composition of organic matter, rates of N cycling and the emission of N_2O from irrigated and non-irrigated pasture soils with similar mineralogy by variable organic matter contents. The main hypothesis tested was that greater emissions of N_2O would occur on soils with higher organic matter contents and in relation to the chemistry of that organic matter.

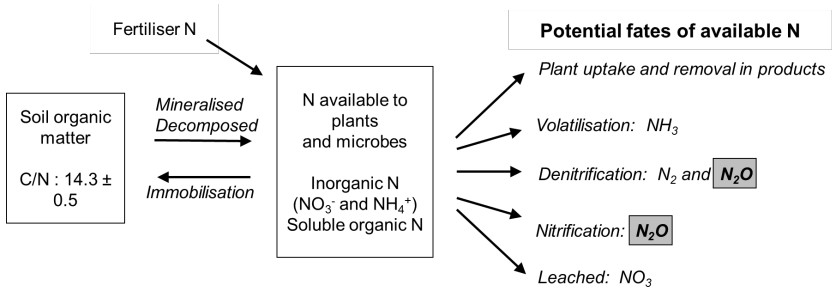

Figure 1. Schematic diagram showing how soil organic matter dynamics can influence the status of available N (soluble organic N, ammonium and nitrate) and how the potential generation of nitrous oxide (N_2O) by biologically mediated processes.

Methods

Soil with different organic matter, organic C and total N contents but similar mineralogy were collected by sampling within and outside the boundary of centre-pivot irrigated pastures in SE South Australia. At eight

different locations, four replicate soil samples were collected from the 0-5 cm soil depth layer within and outside the irrigated zone giving a total of 64 samples. For each replicate sample, five 8 cm diameter cores were composited to produce a sample for N pool and flux rate characterisation. A separate 5 cm diameter intact core from the 0-5 cm soil depth was collected for use in estimating potential N_2O emissions. Soil organic C and total N were quantified by dry combustion, and the chemical composition of soil organic C was quantified using solid-state ^{13}C nuclear magnetic resonance spectroscopy as described by Baldock *et al.* (2013). Soil solution was extracted by centrifugation (Giesler and Lundström 1993) and the contents of various forms of nitrogen and fluxes of N cycling processes were quantified. Microbial biomass C, N and C/N were quantified following fumigation with $CHCl_3$. N fluxes including DON uptake and mineralisation using ^{14}C-labelled tracers (Farrell *et al.* 2013; Farrell *et al.* 2014), net- and potential- N mineralisation (Curtin and Campbell 2008), proteolysis (Hofmockel *et al.* 2010), and denitrification potential (Dury *et al.* 2008) were measured. Production of N_2O was quantified on intact cores incubated at 22°C over a period of one week while maintained at a gravimetric water content (35±8%, mean ± standard deviation).

Results and discussion

Gravimetric contents of organic C, total N, and indices of soil N cycling were differentially influenced by the sampling location, irrigation treatment and an interaction between the two (Table 1). Soil organic C was higher under irrigation compared to non-irrigated at 5 of the 8 locations. At the other three location, although not significant, two locations had higher soil organic carbon content under irrigation and at one location this trend was reversed. For total N content, the irrigated soils had higher values than the dryland soils (7.0 versus 5.5 mg N/g soil, respectively). No impact of irrigation was obtained on available NH_4-N or NO_3-N or on dissolved organic N. The C/N ratio was also not affected by irrigation treatment (10.7 versus 10.5 for dryland and irrigated soils respectively). These results indicate that subsequent quantification of potential N_{min} and total N_2O emission would not be impacted by a fixed effect of irrigation on the initial status of N available to soil microorganisms.

The ^{13}C NMR spectra acquired (Figure 2) for the dryland and irrigated soils were similar in many respects; however, the dryland spectra indicated a greater average extent of decomposition as defined by the Alkyl/O-alkyl ratio (Figure 3) (Baldock et al. 1997). Non-metric multidimensional scaling (nMDS) analyses were used to assess whether the irrigation treatment resulted in differences in soil organic C chemistry or the N status and cycling parameters measured (Figure 4a and b, respectively). Although some overlap of dryland and irrigated soils existed, there was a tendency for the soils from each treatment to separate (consistent with the ANOVA results in Table 1).

Table 1. Irrigation treatment on soil organic C, total N, available ammonium and nitrate, soluble organic N, potential N mineralisation (N_{min}) and total N_2O emission over a one week incubation.

Irrigation treatment		Organic C content (mg/g)	Total N content (mg/g)	NH_4-N (mg/kg)	NO_3-N (mg/kg)	Dissolved Organic N (mg/kg)	Potential Net N_{min} (µg N/kg)	Total N_2O (µg N/kg)
Dryland		58.3	5.5	0.46	4.06	0.82	81.4	0.78
Irrigated		72.6	7.0	0.12	2.83	0.97	111.6	3.14
ANOVA [1]	Location (n=8)	**<0.001**	**<0.001**	0.506	0.066	**0.005**	**0.013**	**<0.001**
results	Irrigation (n=2)	**<0.001**	**<0.001**	0.616	0.211	0.300	**0.001**	**0.010**
(p value)	Loc x Irr	**0.036**	0.062	0.397	0.324	0.062	0.680	0.231

[1] ANOVA results provided for potential N_{min} and total N_2O were obtained using log transformed data to meet the assumption of homogeneity of variance.

Potential net N mineralisation varied across the locations and was affected by the irrigation treatment with a greater amount of N being mineralised (111.6 versus 81.4 µg N/kg soil) and delivered to the inorganic N pool for the irrigated soils. The implication of this finding is that more inorganic N would be available to the biological processes of nitrification and denitrification that are responsible for N_2O emission (Figure 1).

Total N_2O emission from the intact soil cores were different across locations but also influenced by irrigation treatment. In the irrigated soils were N cycling processes were greater, more N_2O was emitted (3.14 versus

0.78µN/kg soil for irrigated and dryland, respectively). In addition the rate of N_2O emission over the entire period was also greater for the irrigated than dryland soils (Figure 5).

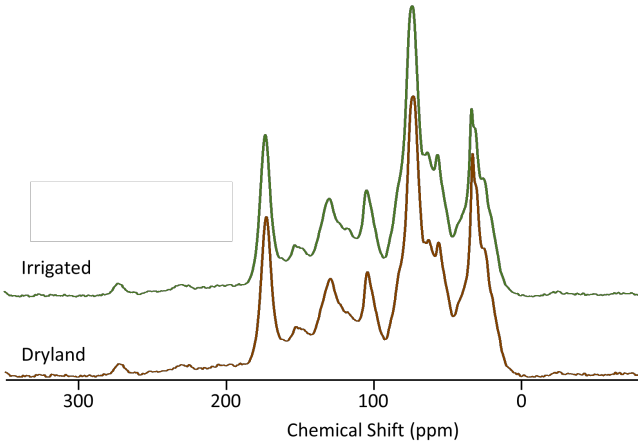

Figure 2. Average ^{13}C NMR spectra acquired for the irrigated and dryland and pasture soils

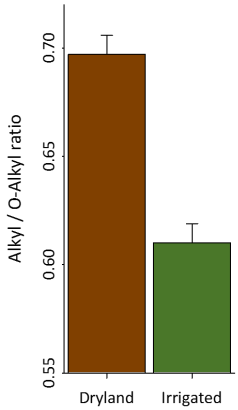

Figure 3. Alkyl/O-alkyl C ratios derived from dryland and irrigated pasture soils

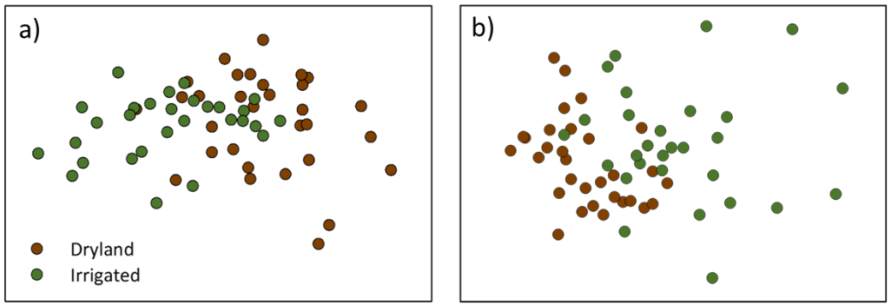

Figure 4. Results of an nMDS analysis of a) the proportion of NMR signal intensity found in the various spectral regions and b) the results of the various N cycling rate measurements

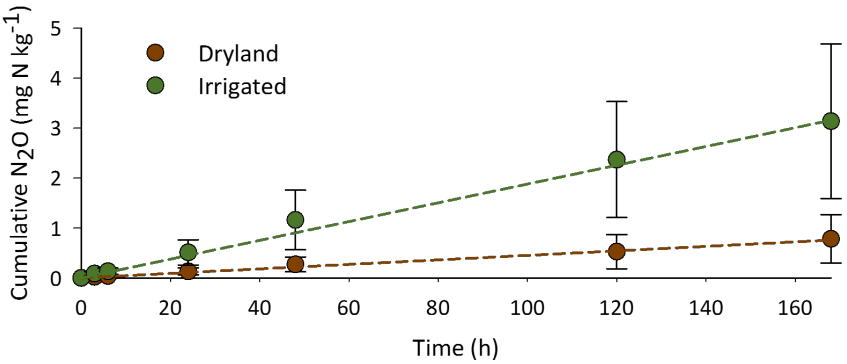

Figure 5. Average temporal emissions of N_2O from dryland and irrigated soils over a one 170 hour incubation.

Conclusion

Increased soil organic carbon contents associated with the irrigated soils led to greater rates of N cycling and increased emission of N_2O. This finding supports the modelling based prediction of (Zaehle *et al.* 2011) that increasing stores of organic carbon in soil may be at least partially offset by higher rates of N_2O emission. It will be critical for soil carbon accounting practices rewarding sequestration of CO_2-C to account for enhanced N_2O emissions to accurately assess the net greenhouse gas balance of the applied activities.

References

Baldock J, Sanderman J, Macdonald L, Massis A, Hawke B, Szarvas S, McGowan J (2013) Quantifying the allocation of soil organic carbon to biologically significant fractions. Soil Research 51, 561-576.

Cleveland CC, Liptzin D (2007) C:N:P stoichiometry in soil: is there a "Redfield ratio" for the microbial biomass? Biogeochemistry 85(3), 235-252.

Curtin D, Campbell C (2008) Mineralizable Nitrogen. In 'Soil Sampling and Methods of Analysis.' 2nd Edition edn. (Eds M Carter and E Gregorich) pp. 599-606. (CRC Press: Boca Raton, FL, USA).

Dury C, Myrold D, Beauchamp E, Reynolds W (2008) Detnitrification techniques for soils. In 'Soil Sampling and Methods of Analysis.' 2nd Edition edn. (Eds M Carter and E Gregorich) pp. 471-493. (CRC Press: Boca Raton, FL, USA).

Farrell M, Hill PW, et al. (2013) Oligopeptides Represent a Preferred Source of Organic N Uptake: A Global Phenomenon? Ecosystems 16(1), 133-145.

Farrell M, Prendergast-Miller M, Jones DL, Hill PW, Condron LM (2014) Soil microbial organic nitrogen uptake is regulated by carbon availability. Soil Biology and Biochemistry 77, 261-267.

Giesler R, Lundström U (1993) Soil Solution Chemistry: Effects of Bulking Soil Samples. Soil Science Society of America Journal 57(5).

Hofmockel KS, Fierer N, Colman BP, Jackson RB (2010) Amino acid abundance and proteolytic potential in North American soils. Oecologia 163(4), 1069-1078.

Kirkby CA, Kirkegaard JA, Richardson AE, Wade LJ, Blanchard C, Batten G (2011) Stable soil organic matter: A comparison of C:N:P:S ratios in Australian and other world soils. Geoderma 163(3-4), 197-208.

Zaehle S, Ciais P, Friend AD, Prieur V (2011) Carbon benefits of anthropogenic reactive nitrogen offset by nitrous oxide emissions. Nature Geoscience 4(9), 601-605.