Soil N_2O fluxes are low from a grain-legume crop grown in a semi-arid climate

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Abstract

Understanding nitrous oxide (N_2O) fluxes from grain-legume crops in semi-arid and arid regions is necessary if we are to improve our knowledge of global terrestrial N_2O losses resulting from biological N fixation. Nitrous oxide fluxes were measured from a rain-fed soil, cropped to grain-legume in a semi-arid region of south-western Australia for one year on a sub-daily basis. The site included plots planted to narrow-leafed lupin (*Lupinus angustifolius*; 'lupin') and plots left bare ('no lupin'), with no N fertiliser applied to treatments. Fluxes were measured using soil chambers connected to a fully automated system that measured N_2O using gas chromatography. Daily N_2O fluxes were low (-0.5–24 g N_2O-N/ha day^{-1}), not different between treatments, and culminated in an annual loss of 118 g N_2O-N/ha. Greatest daily N_2O fluxes occurred during the post-harvest period, and following a series of summer rainfall events. At this time of the year soil conditions were conducive to soil microbial N_2O production: elevated soil water content, available N, and warm soil temperatures (>25 °C). To the best of our knowledge, this is the first paper to report annual N_2O emissions from a rain-fed, grain legume crop in a Mediterranean-like semi-arid region.

Key Words

Greenhouse gas, nitrogen fixation, agriculture, soil nitrogen, plant residue.

Introduction

Legume crops contribute valuable nitrogen (N) inputs to farming systems throughout the world. Conservative estimates suggest cultivated crop and pasture legumes provide 33 to 55 Mt N to agriculture on a global basis, despite the progressive replacement of legume rotations with synthetic N fertilisers over the past four decades (Crews and Peoples 2004; Smil 2001). Nitrogen fixed by legumes contributes to human food production, via fresh pods and dry grains, or as a feedstock and pasture for animals. Non-N fixing crops have been shown to benefit from legume crops through a variety of mechanisms including soil N inputs, disease breaks and improved soil fertility (Peoples *et al.* 2008). However, N fixation by cultivated legumes is also considered to enhance anthropogenic N_2O emissions (Stehfest and Bouwman 2006).

Nitrous oxide fluxes from legume crops is mainly derived from decomposition of the above- and below-ground legume residues, with losses from the biological N-fixation process *per se* considered to be negligible (Rochette and Janzen 2005). Nitrogen released from legume residues is at risk of being emitted as N_2O via a number of soil biological processes including nitrification, denitrification and nitrifier denitrification (Wrage *et al.* 2005). These soil biological processes, and the emission of N_2O, are greatly enhanced by increased N availability. Although estimated N_2O emissions appear low into relation to legume residue inputs (1.25% of N fixed) (IPCC 2006), the high global warming potential of N_2O (298 times greater than CO_2) means accurate estimates are required when assessing net greenhouse gas fluxes from legume based systems.

Legumes systems are estimated to emit 0.4 Mt N_2O-N annually, around 10% of total anthropogenic N_2O emissions, however this value is largely estimated from studies conducted in temperate agricultural systems (Stehfest and Bouwman 2006). Legume crops are widely grown in semi-arid and arid regions, which constitute one third of the global land area (Harrison and Pearce 2000). Yet, N_2O fluxes from legume crops grown in the absence of synthetic N or organic N inputs does not appear to have reported for these regions (Rochette and Janzen 2005; Stehfest and Bouwman 2006). Our understanding of global N_2O fluxes from legume crops would be improved by investigated losses from semi-arid and arid agricultural systems.

The south-western Australian grain belt includes 18 million ha of semi-arid land, and is responsible for 40% of Australia's annual grain production. The region has a strong seasonality characterised by cool, wet winters and hot, dry summers. The aim of the following study was to acquire a unique, one year data set of continuous sub-daily N_2O fluxes from a rain-fed, grain-legume (lupin) crop grown in a semi-arid region, and at the same time investigates the relationship between N_2O fluxes and other soil/environmental parameters.

Materials and methods

Soil and site

Nitrous oxide fluxes were measured on the Cunderdin Agricultural College (31°36′ S, 117°13′ E), in the central wheat belt of Western Australia, approximately 156 km east of Perth. Cunderdin has an annual rainfall of 365 mm, which mainly falls during the winter months (June–August), a mean daily maximum temperature of 25.1 °C and a mean daily minimum temperature of 11.4 °C. The experimental site was located on flat to gently undulating land, and consisted of a free-draining sand overlying a poorly draining clay (Natric Haploxeralf and Typic Natrixeralf; USDA, 1992). The surface soil (0–120 mm) had a pH of 6.0 (1:5 soil : 0.01 M $CaCl_2$ extract), electrical conductivity (EC) of 170 µS cm^{-1} (1:5 soil : water extract), cation exchange capacity of 3.3 cmol/kg, C concentration of 9.38 mg/g, N concentration of 0.76 mg/g and bulk density of 1.4 g cm^{-3}. The surface soil contained 93% sand, 4% silt, and 3% clay. For site history details see Barton *et al.* (2008).

Experimental design and approach

Plots (105 m^2 per plot) were planted to narrow-leafed lupin (*Lupinus angustifolius* cv Mandelup) on the 14th May 2008, with no prior cultivation. A completely randomised design with two treatments, and three replicates, was employed. Plots were either planted with inoculated and fumigated narrow-lupin seed 'lupin') or remained unplanted ('no lupin'). The lupin plots were topdressed with 100 kg/ha of K_2SO_4, and direct-drilled (to 30 mm) with 100 kg/ha of 'Superphosphate CuZnMo'® at planting; no N fertiliser was applied to either treatment. An area (6.76 m^2) within each plot was designated for measuring N_2O fluxes, while the remainder of the plot was used for soil sampling. Four weeks after seeding, plant numbers in the chamber base areas were adjusted, by either removing or adding seedlings, to reflect the average plant density in the field (32 plants m^{-2}). Lupin was harvested from the chambers on the 5th November 2008 and the stubble was retained for the remainder of the study.

Nitrous oxide, soil and climatic measurements

Nitrous oxide fluxes were measured for approximately one year (14th May 2008–28th April 2009) using soil chambers (one per plot) connected to a fully automated system. The system included a gas chromatograph fitted with a ^{63}Ni electron capture detector for N_2O analysis, an automated sampling unit for collecting and distributing gas samples, and six chambers (one per treatment plot). Chambers (500 mm x 500 mm) were placed on metal bases inserted into the ground (100 mm), and fitted with a top that could be automatically opened and closed. Four bases were located in each treatment plot to enable the chambers to be moved to a new position every week so as to minimise the effect of chambers on soil properties and plant growth. The height of the chambers was progressively increased to accommodate crop growth, with a maximum height of 650 mm, and opened if the air temperature in the chamber exceeded a set value (43 °C when lupin was growing in the chamber, 60 °C at other times) or if it rained (> 0.4 mm in five minutes). For further details of automatic gas sampling system see Barton *et al.* (2008).

Soil mineral N, water-filled pore space (WFPS) and climatic variables were measured to explain seasonal variations in N_2O fluxes. The mineral N of the surface soil (0–50 mm) was measured at least every two weeks. Mineral N was extracted from soil samples by adding 80 ml of 1 M KCl to 20 g of field-moist soil (sieved < 4 mm) and shaking for 1 h. The filtered solution (Adventec 5C) was frozen until analysed for NO_3^- and NH_4^+ colorimetrically using a modified hydrazine reduction method (Downes 1978). Gravimetric soil water content was determined at the same time soil samples were collected for mineral N, and after drying sub samples at 105 ºC for at least 24 h. Water-filled pore space was calculated by dividing volumetric water content by total porosity (Linn and Doran 1984). All climatic and soil temperature data from the weather station were collected and stored automatically by the weather station.

Data analyses

A general linear model (using completely randomised design) in Genstat (2007) was used to determine if annual N_2O fluxes varied between the lupin treatments. Post-hoc pair-wise comparisons of means were made using LSD (significance level of 5%). Hourly N_2O (µg N_2O-N m^{-2}/h) fluxes were calculated from the slope of the linear increase in N_2O concentration during the chamber lid closure period, and corrected for chamber air temperature, air pressure and the ratio of cover volume to surface area (Barton *et al.* 2008). Daily losses for each plot were calculated by averaging hourly losses for that day. Annual fluxes for each plot were calculated by integrating hourly losses with time.

Results

Environmental conditions

A total of 299 mm fell at the site during the study period (14th May 2008–28th April 2009), of which 206 mm fell during the period between planting and harvesting the lupin (Figure 1). The 2008 annual rainfall (304 mm) was 83% of the 30-year average (1971–2000), while rainfall during the growing season (May 2007–Oct. 2007) was 82% of the 30-year average. Mean minimum daily air temperature was 9.5 °C and mean maximum daily air temperature was 25.8 °C. The lowest hourly air temperature (-1.4 °C) was recorded in June 2008, while the greatest maximum hourly temperature (45 °C) was recorded in January 2009. Average daily soil temperatures in the surface 100 mm ranged from 9 to 37 °C. Temperatures were lowest during July 2008 (mid-winter) and greatest in January 2009 (mid-summer).

Mineral N and WFPS

The amount of mineral N (NO_3^- and NH_4^+) in the surface soil (0–50 mm) varied during the year, and in a similar way for both treatments (Figure 1). Soil mineral N were greatest for the first two months following planting (May–July 2008), and then again in following successive summer rainfall events following harvest (November 2008 – April 2009; Figure 1). In winter (July), the amount of mineral N in both lupin treatments declined to < 5 kg N/ha (Figure 1). A large proportion of mineral N in the surface soil was in the NO_3^- form, rather than $NH_4^{+.}$ For example, soil NO_3^- in both treatment ranged from <1 to 48 kg N/ha, while the soil NH_4^+ ranged from <1 to 8 kg N/ha (data not shown). Soil WFPS varied seasonally in response to rainfall, and varied from <2 to 39% (data not shown).

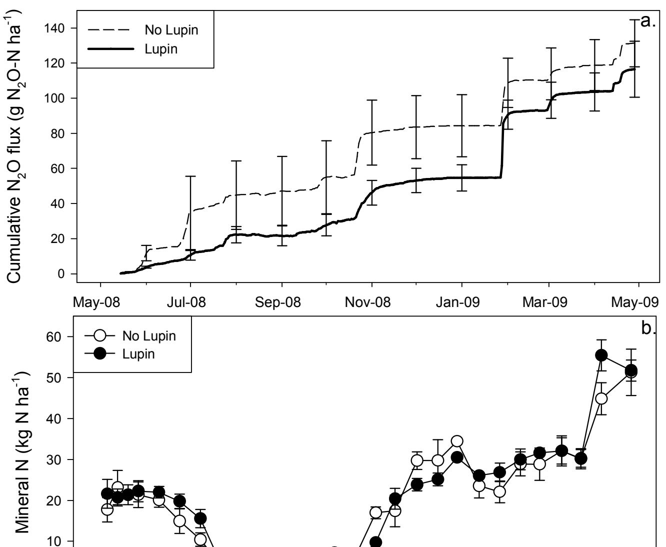

Figure 1. Cumulative daily N_2O fluxes (a), soil mineral N contents (b), and daily precipitation with time at a cropped site at Cunderdin, Australia (14th May 2008–28th April 2009). Values in plots (a) and (b) represent means (± standard errors) of three replicates. Standard errors only shown monthly for plot (a) for clarity.

N_2O fluxes

Daily N_2O fluxes ranged from -0.5 (October 2008) to 24 g N_2O-N/ha day^{-1} (January 2009) in the lupin treatment, and -0.7 (August 2008) to 10 g N_2O-N/ha day^{-1} (January 2009) in the no lupin treatment (Figure 1). Daily N_2O fluxes from the lupin treatment were greatest during summer and autumn following rainfall events ≥ 5 mm day^{-1}. Fluxes from the no lupin treatment also increased following summer and autumn rainfall, but similarly high fluxes were also reported from the no lupin treatment in response to rain (≥ 5 mm day^{-1}) in July and October. Hourly N_2O fluxes following summer and autumn rainfall events tended to peak on the day of rain, or the day following; with greater losses from the lupin treatment than the no lupin treatment. For example on the 29 January 2009, mean hourly N_2O fluxes following summer and autumn rainfall were as high as 164 µg N_2O-N m^{-2} hr^{-1} (standard error, 8 µg N_2O-N m^{-2} hr^{-1}) for the lupin treatment and 95 µg N_2O-N m^{-2} hr^{-1} (standard error, 27 µg N_2O-N m^{-2} hr^{-1}) for the no lupin treatment. Greatest hourly N_2O fluxes following summer rainfall occurred after the first rainfall event, and was not exceeded by subsequent rainfall of similar magnitude. The total amount of N emitted as N_2O after almost one year (351 days) did not differ between the lupin and no lupin treatment, with an average of 118 g N_2O-N/ha ($P<0.05$) (Figure 1). For the lupin treatment, a large proportion (58%; 68 g N_2O-N/ha) of the emissions occurred post-harvest, whereas for the no lupin treatment only 33% (44 g N_2O-N/ha) of the annual loss occurred post-harvest. However, post-harvest cumulative N_2O losses did not vary between treatments ($P<0.05$).

Conclusions

This study is the first to report daily N_2O fluxes from a rain-fed, legume crop grown in a semi-arid region without N fertiliser, and in the absence of grazing animals. Daily N_2O fluxes were low (-0.5–24 g N_2O-N/ha day^{-1}), not different between the legume cropped or bare soil, and culminated in an annual loss of 118 g N_2O-N/ha. Greatest daily N_2O fluxes occurred when the soil was fallow, and following a series of summer rainfall events. The contribution of the biological N fixation process to N_2O emissions appeared negligible, while N_2O emissions from the decomposition of legume crop residue following harvest were also low.

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