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Rainfall variability drives interannual variation in N_2O emissions from a humid, subtropical pasture

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HIGHLIGHTS

- Cumulative emissions averaged 1826.7 ± 199.9 g N_2O-N ha^{-1} yr^{-1} over the two years
- N_2O loss over summer was 46% lower in 2007 than 2008, despite twice the rainfall
- Over 48% of the total N_2O emitted was lost in just 16% of measurement days.
- Errors from weekly sampling data subsets were up to 34% of the sub-daily mean
- morning sampling was best in the pasture, noon in the shaded rainforest and lychee

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ABSTRACT

Variations in interannual rainfall totals can lead to large uncertainties in annual N_2O emission budget estimates from short term field studies. The interannual variation in nitrous oxide (N_2O) emissions from a subtropical pasture in Queensland, Australia, was examined using continuous measurements of automated chambers over 2 consecutive years. Nitrous oxide emissions were highest during the summer months and were highly episodic, related more to the size and distribution of rain events than soil water content. Over 48% of the total N_2O emitted was lost in just 16% of measurement days.

Interannual variation in annual N_2O estimates was high, with cumulative emissions increasing with decreasing rainfall. Cumulative emissions averaged 1826.7 ± 199.9 g N_2O-N ha^{-1} yr^{-1} over the two year period, though emissions from 2008 (2148 ± 273 g N_2O-N ha^{-1} yr^{-1}) were 42% higher than 2007 (1504 ± 126 g N_2O-N ha^{-1} yr^{-1}). This increase in annual emissions coincided with almost half of the summer precipitation from 2007 to 2008. Emissions dynamics were chiefly driven by the distribution and size of rain events which varied on a seasonal and annual basis. Sampling frequency effects on cumulative N_2O flux estimation were assessed using a jackknife technique to inform future manual sampling campaigns. Test subsets of the daily measured data were generated for the pasture and two adjacent land-uses (rainforest and lychee orchard) by selecting measured flux values at regular time intervals ranging from 1 to 30 days. Errors associated with weekly sampling were up to 34% of the sub-daily mean and were highly biased towards overestimation if strategically sampled following rain events. Sampling time of day also played a critical role. Morning sampling best represented the 24 hour mean in the pasture, whereas sampling at noon proved the most accurate in the shaded rainforest and lychee orchard.

1. Introduction

The atmospheric concentration of N_2O reached 324.2 ppb in 2011 and continues to increase at the rate of 0.78 ppb annually (IPCC, 2013). N_2O is very stable in the atmosphere, with a lifetime of 114 years and together with the high cumulative radiative forcing of the molecule leads to a global warming potential (GWP) 310 times that of CO_2 (Forster et al., 2007). It is also the principle gas associated with the destruction of stratospheric ozone. Moreover, high losses of N_2O are indicative of inefficient nitrogen (N) cycling in agricultural systems resulting in potential yield and economic losses which make quantifying losses of N_2O of increasing interest to researchers (Ravishankara et al., 2009).

Nitrous oxide is principally produced in the soil via the microbial processes of nitrification and denitrification as is the release of N and carbon (C) substrates from the organic pool. The timing and magnitude of N_2O emissions are regulated by the availability of mineral N, organic carbon, soil pH, temperature, and most critically, moisture content

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(Firestone and Davidson, 1989; Hutchinson and Davidson, 1993; Scheer et al., 2012). As a result, variability in climatic conditions, particularly rainfall is key in determining N_2O losses on an annual basis. Alternate wet/dry cycles typical of the semi-arid and tropical agricultural landscapes can stimulate N mineralisation from organic matter, promoting NO_3^- accumulation during long dry periods, and promoting increased N_2O production during wetter periods (Groffman and Tiedje, 1988; Davidson et al., 1993; Breuer et al., 2000; Priemé and Christensen, 2001; Dalal et al., 2003; Ruser et al., 2006).

Reported N_2O emissions range between 1.4–14.0 g N_2O-N ha^{-1} day^{-1} from unfertilized tropical pastures (Keller and Reiners, 1994; Mosier and Delgado, 1997; Veldkamp et al., 1998; Erickson et al., 2001; Neill et al., 2005) and 1.3–8.5 g N_2O-N ha^{-1} day^{-1} from Australian subtropical pastures (Weier et al., 1991; Denmead et al., 2000; Dalal et al., 2003; Scheer et al., 2011). While substantial climate driven interannual variations in N_2O emissions have been observed from pastures in temperate environments (Flechard et al., 2007; Rafique et al., 2011) and even arid areas (Du et al., 2006), most studies from subtropical or tropical pastures have utilized only comparatively coarse weekly or monthly gas sampling (Keller and Reiners, 1994; Veldkamp et al., 1998; Erickson et al., 2001; Allen et al., 2009) or laboratory incubation experiments (Weier et al., 1993b). Few studies have taken into account interannual variability, which considering the large interannual variations in rainfall associated with the tropical and subtropical regions, can lead to large potential errors in N_2O budget estimations.

The humid subtropical zone of Australia extends from 20°S to 34°S, covering some 3.26 M ha (Department of Trade, 1982), with similar climatic zones found on the south-eastern side of most continents. Mean annual rainfall in this zone ranges from 900–2000 mm and is dominated by the El Niño Southern Oscillation (ENSO) climate pattern (Department of Trade, 1982; Lough, 1991). Rainfall variability across this region is large over monthly, seasonal, interannual and decadal time scales. This can result in long periods of below average rainfall intersected by extremely wet years. Precipitation is also marked by infrequent but extremely large rain events, with fall greater than 300 mm in 24 h not uncommon. Consequently annual rainfall distribution and annual totals can vary greatly (Murphy and Ribbe, 2004), with some individual locations within the climatic zone recording mean annual precipitation totals ranging from 793 mm to 3039 mm (Bureau of Meteorology, 2009).

Improved pasture for livestock grazing is the largest agricultural land use in this region accounting for 40 — 50% of the total area. Naturalised and sown legume species can contribute large amounts of N to the soil/plant system in unfertilized pastures and are critical in maintaining productivity. Estimates of N fixation rates in legume based pastures are in excess of 200 kg N ha^{-1} yr^{-1}, though their total contribution to the livestock industry is difficult to obtain because of uncertainties in the distribution and productivity of leguminous pastures (Weier, 1994; Peoples and Baldock, 2001). Since grass–legume mixtures also have the potential to increase rates of N cycling, this can also result in an increase in N_2O emissions (Erickson and Keller, 1997).

The present study represents one of the first field datasets of continuous high resolution greenhouse gas flux rates from pasture systems in the tropical and subtropical climatic zones. The objectives of the study are to (i) provide a robust N_2O budget from an unfertilised subtropical pasture, (ii) estimate the interannual variability of N_2O emissions under consistent management and (iii) examine the main drivers of variability between the seasons over the two year measurement period.

2. Methods and materials

2.1. Study site

The study site was located on the alluvial flood plain of the Mooloolah Valley (latitude: 26.00; longitude: 152.00) 20 km inland (west) of the Sunshine Coast shoreline and 100 km north of Brisbane, Australia. As with the majority of the region, the study site was converted to improved pasture after the felling of the native rainforest in the early 1900s to make way for dairy and beef production. The current pasture had been established approximately 30 years and its botanical composition consists of the tropical grass *Setaria sphacelata* with the legume Silverleaf Desmodium (*Desmodium uncinatum*) dominant during the summer and White Clover (*Trifolium repens*) in the cooler months. No nitrogenous fertilizer had been applied to the pasture site in the last 20 years.

The soil at the site was formed on the alluvial plain of the Mooloolah River and is classified according to the Australian Soil Classification as a Haplic, Eutrophic, and Black Dermosol (Isbell, 2002). Soil texture at the site was classified as a loam. The C:N ratio of the pasture biomass averaged 15.6, and changed little over the course of the experiment. A full list of soil properties is given in Table 1.

The mean annual rainfall of the region is 1709 mm (Bureau of Meteorology, 2009). Summers are typically warm and wet, and winters cool and dry. Although the majority of precipitation occurs in the summer months (December to February), both significant rainfall events and extended dry periods are common year round. Mean daily temperatures range from a minimum of 14 °C to a maximum of 25.8 °C, with infrequent frosts occurring in the winter (June to August) months. The mean annual evaporation rate is 1400 mm.

2.2. Experimental design

Two full years of high temporal resolution soil, plant growth and N_2O emission data were collected from the 1st of March 2007 to the 28th February 2009. For ease of interpretation, data from the 1st March 2008 is referred to as the 2008 measurement year. Measurements are expressed on a seasonal basis representing March to May for autumn, June to August for winter, September to November for spring and December to February for summer.

Soil gas fluxes were measured utilizing the static closed chamber technique (non-steady-state, non-through-flow) using the same automated gas sampling system described in detail by Rowlings et al. (2012). The system consisted of automated, pneumatically operated measuring chambers linked to a sampling control system and a gas chromatograph. The acrylic glass chambers covered a surface area of

Table 1
Selected site characteristics for subtropical pasture at Mooloolah, Queensland.

Parameter	
Coordinates	152° 93′ E 26° 45′ S
Height above sea level	60 m
Slope	1–2°
Principle pasture species	*Setaria sphacelata*
Secondary pasture species	*Trifolium repens* *Desmodium uncinatum*
C:N ratio, pasture	15.6
Soil parent material	Alluvium
Soil type	Dermosol
Texture class	Loam
Fine sand (<0.25 mm)	27.8%
Coarse sand (>0.25 mm)	9.5%
Silt	44.3%
Clay	18.4%
Bulk density 0–10 cm	1.0 g cm^{-3}
10–20 cm	1.4 g cm^{-3}
Field infiltration rate	26.1 ± 12.5 cm h^{-1}
pH	5.5
Electrical conductivity	0.1 ds cm^{-1}
CEC	20.6 cmol(+)/kg
Total nitrogen	0.3%
C:N ratio, soil	9.6
Total organic carbon	2.8%
Charcoal carbon	0.2%
Particulate carbon	2.1%