Effect of reduced deficit irrigation and split urea application on N_2O production and emissions in a sorghum crop: A lysimeter study

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Abstract

Nitrous oxide (N_2O) emissions derived from N fertilisers applied to agricultural soils are the largest source of N_2O in Australia. In this study we tested the hypothesis that applying irrigation at a reduced deficit (RED) and splitting urea into two applications (SPLIT), would reduce N_2O emissions compared with the conventional practice of applying irrigations at larger deficits (CONV) and a single in-crop urea application. CONV treatments received four irrigations of 100 mm each and RED treatments received eight irrigations of 50 mm each. Urea treatments included a single application of 280 kg N ha^{-1} and two applications of 140 kg N ha^{-1} each (SPLIT). Nitrous oxide emissions from the soil surface were measured continuously and N_2O concentration in soil pore space was measured periodically at 5 cm, 30 cm, 60 cm and 90 cm depths. Differences in total N_2O emissions over the season were not significant among treatments. Peaks in N_2O emissions were measured following irrigations. These peaks were higher in magnitude in CONV treatments during the early season irrigations and during late season higher magnitudes were detected in RED treatments. Highest N_2O concentrations were consistently measured in the top soil layer. Plant N uptake and biomass were similar among treatments. Leaching losses were small and mostly observed in cores that received 100 mm irrigations.

Keywords

Nitrous oxide, soil profile.

Introduction

The agriculture sector is the largest source of N_2O emissions in Australia, emitting 76% of total N_2O emissions in 2008 (DCCEE 2010). Such emissions are mainly derived from the N fertilisers applied to agricultural soils. The production, consumption and emission of N_2O is regulated by a complex range of microbial processes (Butterbach-Bahl et al. 2013), with nitrification and denitrification being the two major processes responsible for N_2O emissions from soil. In irrigated systems, total N_2O emissions are dominated by large pulses driven by denitrification following irrigation applications, or rainfall events, especially when mineral N is not limiting (Jamali et al. 2015; Scheer et al. 2008). Accurately matching crop demand for water and mineral N may help mitigate N_2O emissions from irrigated systems by reducing substrate availability to microbes and the duration over which soils experience anaerobic conditions.

In this study we tested the hypothesis that applying irrigation at a reduced deficit and splitting urea into two applications, would reduce N_2O emissions compared with the more usual practice of applying irrigations at larger deficits and a single urea application.

Methods

Lysimeter and automated N_2O measurement system

The lysimeter facility used in this study has been described in detail elsewhere (Jamali et al. 2015). Twelve intact soil cores (0.7 m diameter x 1.2 m height) were collected from a soil locally known as Mundiwa Clay Loam located in the lower part of the Riverine Plain near Yanco, NSW (Lat. -34.603242, Long 146.382000). The soil is classified as *Chromosol* (Isbell 2002). Bulk density was 1.27 g cm^{-3} in the surface layer (0-10 cm) and increased with depth. Mineral N and organic carbon decreased with depth. Lysimeter cores were fitted with automated chambers of the same diameter as the cores for near-continuous measurements of N_2O. These chambers were connected to a sampling unit and gas chromatograph (GC, SRI8610, Torrance, CA, USA) for collecting and analysing gas samples.

N_2O concentration in soil profile

Nitrous oxide concentration in soil pore space was measured at 5 cm, 30 cm, 60 cm and 90 cm depths in two cores per treatment using 30 cm long x 0.55 cm inner diameter hydrophobic capillary membrane sampling tubes (ACCUREL® PP V8/2HF, Wuppertal, Germany) fitted with a stopcock for collecting gas samples in pre-evacuated glass vials. The samples were analysed using GC.

Agronomic treatments

A week prior to sowing, all cores were irrigated and drained ensuring the soil was equilibrated and that the soil profile was close to field capacity. On the day of sowing (i.e. 22nd December 2014), 20 kg N ha^{-1} as diammonium phosphate (DAP) was applied by mixing within the upper 5 cm of soil. Final number of grain sorghum (*Sorghum bicolor*; variety: MR-Taurus) plants was maintained at six plants per chamber by thinning after germination. Sorghum plants were harvested on 1st April, 2015 and analysed for total N using a ShimadzuTM TOC-L analyser. Leachate was collected and volume measured at least once a week and analysed for mineral N.

The treatments applied included conventional irrigation with single urea application (CONV), conventional irrigation with split urea application (CONV-SPLIT), reduced deficit irrigation (RED) with single urea application and reduced deficit irrigation with split urea application (RED-SPLIT). The CONV irrigation treatments received four irrigations of 100 mm each fortnightly while RED treatments received eight applications of 50 mm each weekly in the post sowing period (Figure 1). Rainfall received after the commencement of irrigation treatments was excluded using a lysimeter shelter. Urea applications included either two applications of 140 kg N ha^{-1} each in SPLIT treatments or a single application of 280 kg N ha^{-1} in the remaining treatments.

Results and Discussion

Nitrous oxide fluxes

Total N_2O emissions in the CONV-SPLIT, RED and RED-SPLIT treatments, were not significantly different from the CONV treatment, which generally represents grower practice (Table 1). A generalised linear mixed model further showed that the effect of irrigation and fertiliser treatments, and their interaction, on N_2O was not significant. Within RED treatments, splitting urea into two applications did not mitigate N_2O emissions which is expected as soil oxygen conditions would have been unsuitable for denitrification in both RED treatments regardless of substrate availability.

Nitrous oxide fluxes remained low (i.e. <10 g N_2O-N ha^{-1} day^{-1}) in the period between sowing and first irrigation application on 27th January, 2015 in all treatments despite urea application on 13th January suggesting that aerobic soil condition was the factor limiting denitrification. The greatest N_2O emissions following the first irrigation were observed in the two CONV treatments compared with the two RED treatments (Figure 1). This confirms the hypothesis that shorter interval irrigation and splitting N application may reduce N_2O losses following irrigation events. In the CONV treatments, the response of N_2O emissions to irrigations (100 mm) diminished as the growing season progressed with negligible effect on N_2O emissions in response to final irrigation on 9th March. Conversely, in the RED treatments, the N_2O response to irrigations (50 mm) was higher later in the season than earlier. Diminished response of N_2O to 100 mm irrigations in CONV treatment later in the season may have been caused by depletion of N substrate through denitrification or increased leaching below the root zone during earlier irrigations. Higher peaks in emissions in the RED treatments as the season progressed may indicate improved matching of fertiliser to crop demand earlier in the season and excess N availability later in the season because of soil N mineralisation. Frequent irrigations in RED treatments would assist N mineralisation by keeping the biologically most active top soil layer moist. Thus N_2O mitigation offered by RED treatments earlier in the season was largely negated by higher N_2O emissions in RED treatments later in the season.

Nitrous oxide concentrations in soil profile

The N_2O concentrations decreased with depth (Figure 2) indicating that most of N_2O production occurred in the top soil layer which also had the highest soil organic carbon, total nitrogen content (TN and TOC data not shown) and lowest bulk density. During the episodes of high N_2O concentrations at 5 cm depth following irrigation applications, the N_2O concentration was always higher in the two CONV treatments compared with the RED treatments. It is difficult to relate these results to N_2O fluxes because of different temporal resolution of measurements and only two out of three replicate cores measured for N_2O concentration.

Table 1. Total N_2O emissions, plant N uptake and leaching losses of mineral N and water during the sorghum growing season 2014-15 showing no significant reductions due to treatments; standard deviations shown in parentheses.

Treatment	Total N_2O (kg N_2O-N ha^{-1})	Biomass (Mg ha^{-1})	N uptake (kg N ha^{-1})	N Leaching (mm)	Water Leaching (mm)
CONV	1.37 (0.61)a	8.5 (1.1)a	135 (10)a	7.8 (7.3)a	17 (15)a
CONV-SPLIT	1.01 (0.27)a	8.8 (2.1)a	127 (26)a	11.6 (20.1)a	49 (86)a
RED	1.16 (0.25)a	9.3 (1.3)a	154 (15)a	0.0 (0.0)a	0 (0)a
RED-SPLIT	1.24 (0.37)a	8.1 (0.8)a	158 (8)a	0.0 (0.0)a	2 (3)a

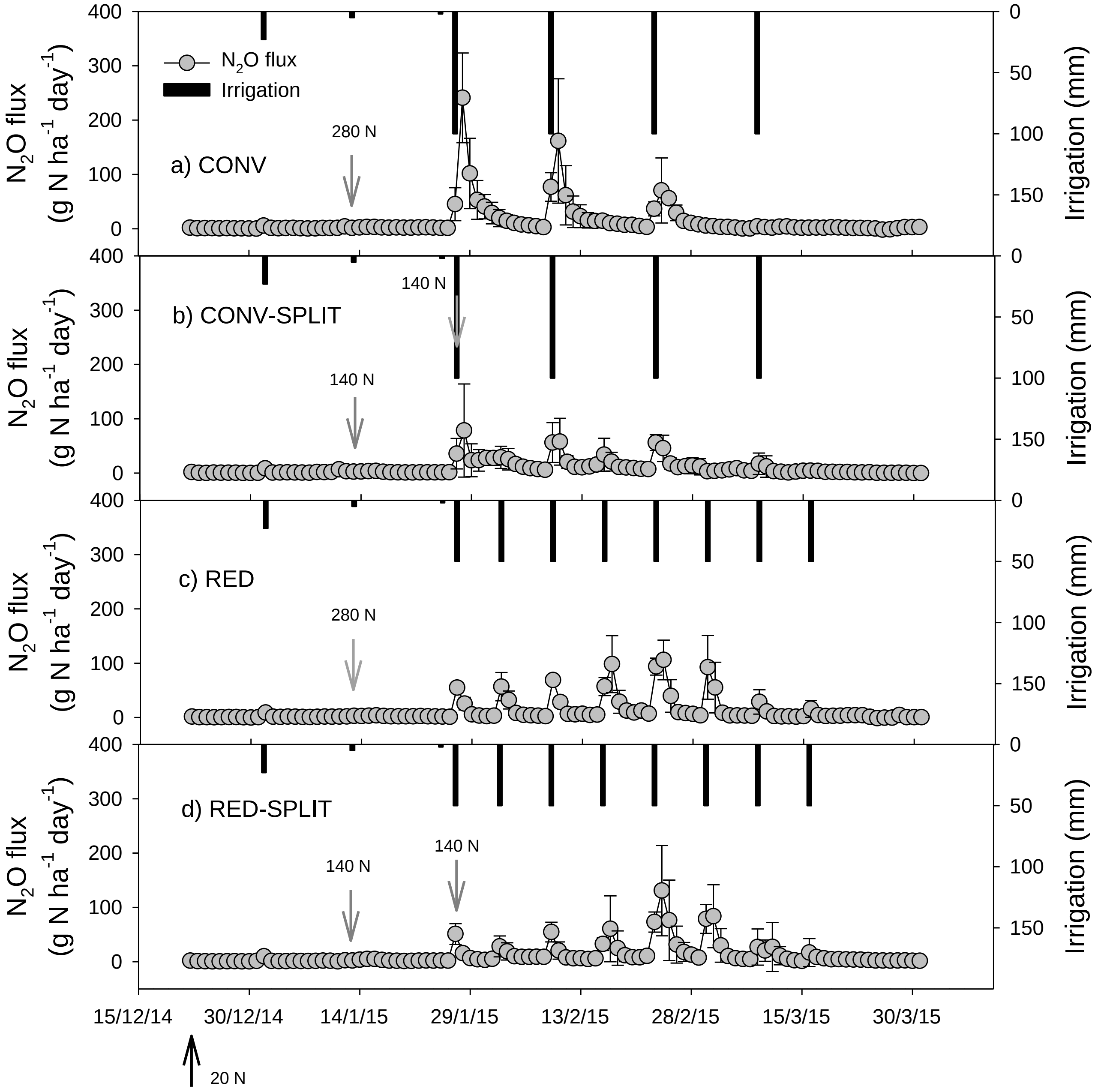

Figure 1. Average daily N_2O fluxes and irrigation applied to the lysimeter cores; error bars are standard deviation of the mean; black arrow under x-axis showing the timing of fertiliser application as DAP and grey arrows showing urea application with text showing the rate in kg N ha^{-1}.

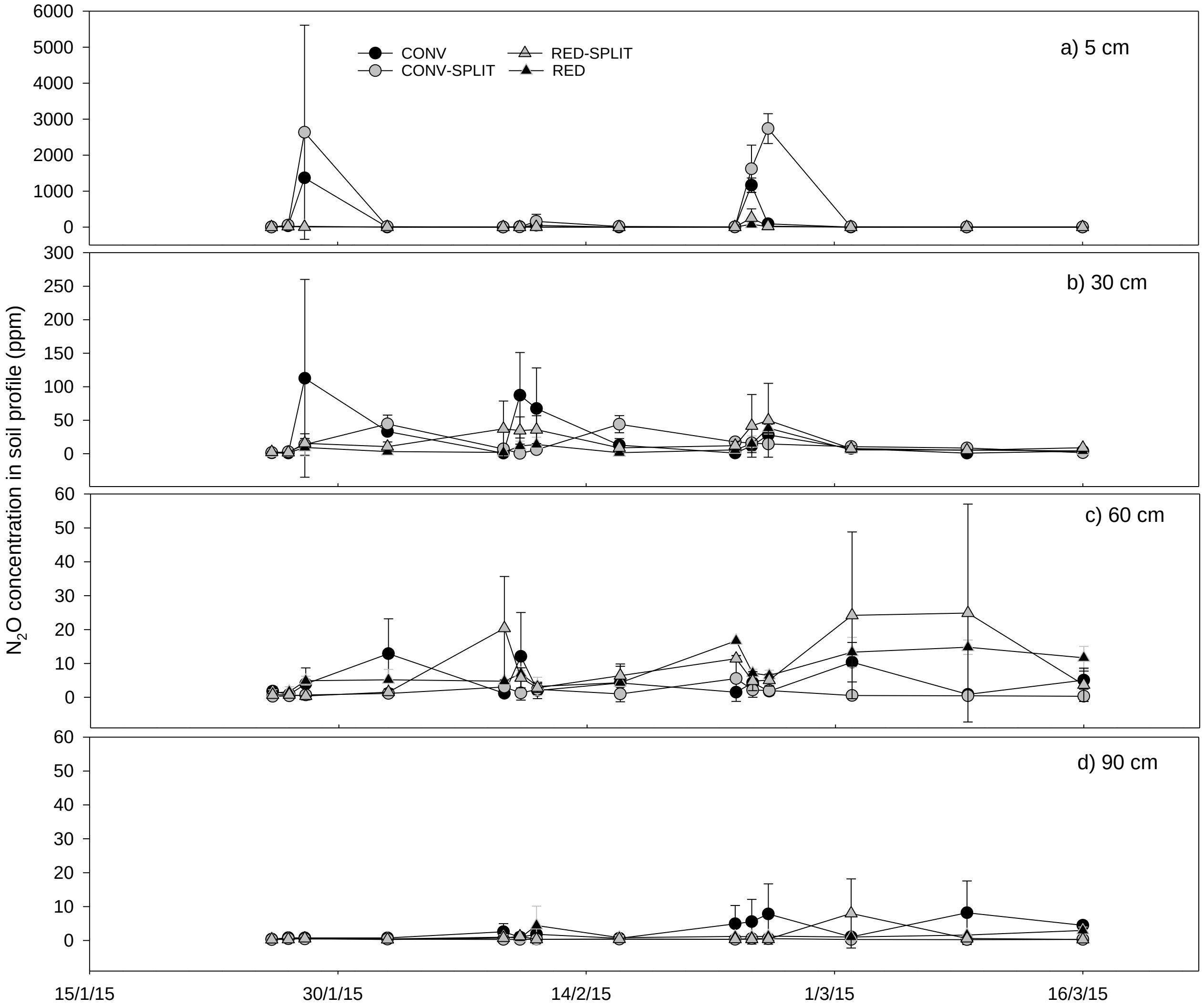

Figure 2. Nitrous oxide concentration at different depths in soil profile; error bars are standard deviation of the mean; note the change in y-axis scale.

Plant N uptake and leaching losses

Plant biomass and plant N uptake were similar among treatments (Table 1) which was expected as none of the treatments were either water- or N-limited. Small leaching losses of water and mineral N were measured in four out of six cores that received 100 mm irrigations (CONV and CONV+SPLIT) and in one out of six cores that received 50 mm irrigations (RED and RED + SPLIT).

Despite large experimental variability, which is common in soil N_2O studies, these results show interesting flux differences that need further investigation in field scale studies.

References

Butterbach-Bahl K, Baggs EM, Dannenmann M, Kiese R and Zechmeister-Boltenstern S (2013). Nitrous oxide emissions from soils: how well do we understand the processes and their controls? Philosophical Transactions of the Royal Society B: Biological Sciences 368, 1621.

DCCEE (2010). Climate change adaptation actions for local government, Department of Climate Change and Energy Efficiency, Canberra.

Isbell R (2002). The Australian soil classification 4. CSIRO publishing.

Jamali H, Quayle WC and Baldock J (2015). Reducing nitrous oxide emissions and nitrogen leaching losses from irrigated arable cropping in Australia through optimized irrigation scheduling. Agricultural and Forest Meteorology 208, 32-39.

Scheer C, Wassmann R, Kienzler K, Ibragimov N and Eschanov R (2008). Nitrous oxide emissions from fertilized, irrigated cotton (Gossypium hirsutum L.) in the Aral Sea Basin, Uzbekistan: Influence of nitrogen applications and irrigation practices. Soil Biology and Biochemistry 40 (2), 290-301.