Agricultural and Forest Meteorology 208 (2015) 32–39

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet

Reducing nitrous oxide emissions and nitrogen leaching losses from irrigated arable cropping in Australia through optimized irrigation scheduling

Hizbullah Jamali[a,*], Wendy C. Quayle[a], Jeffrey Baldock[b]

[a] CSIRO Agriculture Flagship, PMB 3, Griffith, NSW 2680, Australia
[b] CSIRO Agriculture Flagship, PMB 2, Glen Osmond, SA 5064, Australia

ARTICLE INFO

Article history:
Received 15 December 2014
Received in revised form 14 April 2015
Accepted 18 April 2015
Available online 26 April 2015

Keywords:
Irrigation
Nitrous oxide
Sorghum
Lysimeter
Leaching
Water balance

ABSTRACT

Irrigated agriculture may contribute as much as two-thirds to future global food demand because of the high intensity of production that it offers. However, it also has relatively high fertilizer and water inputs and therefore, N_2O emissions. This study examined how varying the volume of individual irrigation events could mitigate N_2O emissions from irrigated grain sorghum in Australia. To maintain productivity, the applied water amount was kept constant over an entire growing season. Treatments included irrigation water applications of 120 mm (3 applications), 90 mm (4 applications), 60 mm (6 applications) and 30 mm (12 applications). A custom-designed automated chamber-weighing lysimeter system was used to measure soil N_2O fluxes, leaching losses and evapotranspiration simultaneously. The cumulative seasonal N_2O emissions (kg N_2O-N ha^{-1} $season^{-1}$) were greatest in the 120 mm (1.71 ± 0.70) and 90 mm (1.81 ± 0.39) treatments and least in the 30 mm (0.88 ± 0.21) treatment. Irrigation management had a significant ($p \leq 0.001$) effect on reducing N_2O emissions by avoiding the high magnitude N_2O pulses that are measured following larger irrigation applications. The losses of water through leaching decreased from $41 \pm 1\%$ in the 120 mm treatment to $12 \pm 4\%$ in the 30 mm treatment while mineral-N losses decreased from 20% in the 120 mm to 3% in the 30 mm treatment. Plant N uptake in the 30 mm and the 60 mm treatments was significantly ($p \leq 0.05$) higher than for the 120 mm treatment. The increase in plant N-uptake and decrease in leaching losses of N in frequent irrigations of ≤90 mm compared with 120 mm irrigations suggests improvements in crop nitrogen use efficiency and potential for productivity gains.

1. Introduction

Atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have increased by 40%, 150% and 20%, respectively, from 1750 to 2011 due to human activity (Stocker et al., 2013). Nitrous oxide is the dominant ozone-depleting substance (Ravishankara et al., 2009) and, with a global warming potential equal to 298 times that of CO_2 over 100 years, contributes significantly to climate change (Forster et al., 2007). Nitrous oxide emissions derived from anthropogenic sources are projected to double by year 2050 according to a business-as-usual scenario (Davidson and Kanter, 2014). Agriculture is the largest source of anthropogenic N_2O emissions representing 60% of such emissions (Syakila and Kroeze, 2011).

The projected increase in human population and consequent need for more food production will likely result in expansion of irrigated agricultural area. It is predicted that nearly two-thirds of future food demand will be met through 306 M ha of land under irrigation because of the potential for higher productivity (FAO, 1996, 2010). In Australia, irrigated land was only 0.5% (2.4 M ha) of total agricultural land in 2003–04 but contributed around one-quarter of the value of all agricultural production because of high value crops grown on irrigated farms – an average irrigated farm generating 55% more production than an equivalent non-irrigated farm (Trewin and Banks, 2006). Higher productivity in irrigated agriculture has been made possible primarily through increased water availability but higher inputs of inorganic fertilizers, including nitrogen (N) have also been required.

Irrigated soils, particularly those receiving additions of inorganic N fertilizer, can have a high potential for emitting N_2O since soil water status is a primary driver regulating soil redox conditions and therefore potential rates of denitrification and

* Corresponding author. Tel.: +61 2 6960 1553; fax: +61 2 6960 1600.
E-mail address: hiz.jamali@csiro.au (H. Jamali).

http://dx.doi.org/10.1016/j.agrformet.2015.04.010
0168-1923/

nitrification – two key processes responsible for N_2O emissions (Butterbach-Bahl et al., 2013; Syakila and Kroeze, 2011).

Since N_2O emissions from agricultural soils are mainly a function of inorganic N applied as fertilizer and soil moisture conditions, these emissions have the potential to be controlled through careful N and water management (Reay et al., 2012). Nitrous oxide emissions over a crop season are dominated by the episodes of denitrification-driven N_2O pulses that occur after irrigation (Trost et al., 2013) or rainfall events (Barton et al., 2013) in the presence of available soil nitrogen. Large N_2O pulses generated immediately after irrigation, especially following a fertilizer application, may represent up to 90% of total N_2O emissions from irrigated soil (Scheer et al., 2008). In irrigated systems, the timing and quantity of irrigation water (and fertilizer) can be controlled which may provide an opportunity for N_2O mitigation. Nevertheless, reducing N_2O emissions from agricultural soils without yield penalties represents a significant challenge. Little information exists pertaining to the use of irrigation management to mitigate N_2O emission.

This study examined how the frequency and volume of irrigation water can be manipulated to reduce N_2O emission from soil supporting a broadacre summer irrigated crop – grain sorghum. The approach taken was to keep the total seasonal volume of irrigation water, typical of what farmers would normally use, but to apply it in smaller more frequent events compared with usual farmer practice of larger less frequent events. We hypothesize that smaller, more frequent irrigation applications may (1) reduce N_2O emissions because soil oxygen levels will stay above the redox potential threshold required for denitrification, (2) reduce leaching losses of N and water below the root zone by better matching irrigations to crop growth requirements, and (3) increase crop N use efficiency by matching water availability to crop requirement and reducing N losses.

1. Material and methods

1.1. Lysimeter facility

The lysimeter facility at the Griffith laboratories of CSIRO can house up to 32 intact soil cores (0.7 m diameter × 1.2 m height). Intact soil cores were collected in 6 mm thick mild steel casings with a cutting edge welded at the bottom. A pneumatic hammer and a crane were used to push the casings into the soil. The soil cores were then pulled out through an excavated side trench with a crane. A perforated polyvinyl chloride (PVC) manifold was attached to the bottom of the core with an outlet for collecting leachates. The space around the PVC manifold was filled with fine sand and the core was sealed by welding a steel plate to the bottom of the core.

Soil cores were collected from Willbriggie (Lat. −34.48, Long. 145.95), about 20 km south of Griffith, New South Wales, Australia in November, 2013. The soil type was locally known as Willbriggie Clay Loam and classified as a Chromosol (Isbell, 2002), and is widely used in irrigated broadacre cropping throughout the Riverina Plain.

For soil characterization, 10 cores of smaller diameter (10 cm diameter × 1.2 m depth) were also collected using a hydraulic corer. Five of the smaller cores were used for determining the bulk density (BD) while the remaining five were bulked and analysed for soil texture (hydrometer method), total carbon (TC), organic carbon (TOC), total nitrogen (TN), mineral nitrogen (MN) and pH. Total carbon, TOC and TN analysis was performed using a Shimadzu® TOC-L analyser. Ammonium (NH_4^+) and nitrate (NO_3^-) was analysed colorimetrically using 2 M KCl extracts, and dissolved organic carbon (DOC) using 0.5 M K_2SO_4 extracts (Voroney et al., 2008) which were analyzed using a LACHAT QuickChem® 8500 flow injection analyser. Soil physical and chemical properties are shown in Table 1.

Fig. 1. Irrigation experiment in progress at CSIRO Griffith lysimeter site with sorghum growing at 3-leaf stage.

The long-term (1962–2014) annual average rainfall, average minimum and average maximum temperatures are 409 mm, 9.6 °C and 25.1 °C, respectively, for the lysimeter site. During the sorghum season (14 January to 30 April, 2014), total rainfall, average minimum and average maximum temperatures were 164 mm, 14.8 °C and 30 °C, respectively.

1.2. Continuous N_2O measurements

Automated chambers (Fig. 1) were used to measure near-continuous fluxes of N_2O, CH_4 and CO_2 (only N_2O data are presented here). The automated chambers (70 cm diameter × 30 cm height), custom designed to fit the round surface area of lysimeter cores, were built in-house using transparent 8 mm thick Perspex® (B&M Plastics Pty Ltd., Yennora, NSW). The height of the chambers can be increased to 90 cm by adding 30 cm extensions to accommodate the growth of plants. The opening–closing mechanism was controlled by electric linear actuators, as opposed to commonly used pneumatic actuators (Livesley et al., 2011), to ensure gentler operation and noise minimization in the weight measurement data for evapotranspiration. An alarm system ensured chambers remain open when rainfall of ≥0.4 mm is received, and/or chamber temperature exceeded 45 °C. The automated chambers were connected to a sampling unit, a CO_2 analyzer and a gas chromatograph (supplied by Queensland University Technology, Australia), details of which are given elsewhere (Breuer et al., 2002; Livesley et al., 2011; Rowlings et al., 2012). The gas chromatograph (GC, SRI8610, Torrance, CA, USA) was fitted with a ^{63}Ni electron capture detector (ECD) for N_2O analysis and a flame ionization detector (FID) for CH_4 analysis. The 12 chambers were divided into three sets of four chambers with each set closing for one hour. During the hour when the chambers were closed the concentration of N_2O, CH_4 and CO_2 was measured at 0, 20 40 and 60 min. Once the gas measurements were completed, the chambers that were being analyzed were opened, the next set of 4 chambers were closed and gas measurements were initiated. It required three hours to complete the gas measurements from all of the 12 chambers which allowed eight measurements per day per chamber. Each sample collection required approximately 3 min. The headspace gas was first passed through an infra-red gas analyser (LI820, LI-COR®, St. Joseph, MI, USA) for CO_2 analysis followed by analysis for N_2O and CH_4 using the GC. A one point calibration was performed by running a mixed calibration standard (0.5 ppm N_2O, 4 ppm CH_4, 500 ppm CO_2) after every four samples. Hourly fluxes for N_2O ($\mu g\ N_2O\text{-}N\ m^{-2}\ h^{-1}$) were calculated by using linear regression and corrected for chamber temperature and