Nitrous oxide emissions from irrigated cotton fields – variations in time and space

Graeme Schwenke and Annabelle McPherson
NSW DPI, Tamworth

Key findings

- Nitrous oxide (N_2O) emission into a closed chamber was found to be linear over our standard closure time of 60 minutes in three of the four chambers tested.
- Beginning N_2O sampling at 9:00–9:30 am appeared to underestimate the daily average N_2O flux, although there was no significant time effect in the higher emitting treatment. The sampling time was changed for the following season to start at 10:00–10:30 am.
- The average flux from the four manual chamber locations used in the main experiments (irrigated furrow, non-irrigated furrow, fertilised side of plant bed, non-fertilised side of plant bed) were found to give a good approximation of the N_2O flux averaged across 12 chambers covering all possible locations in a two metre cross section of the cotton field.
- These tests validated the assumptions made in devising the sampling strategy used in subsequent experiments.

Introduction

Measuring soil nitrous oxide (N_2O) emission involves pushing a chamber into the soil, sealing the chamber for a period of time, then sampling the air within the chamber headspace to measure the increase in N_2O concentration during the sealed period. The length of time that the chamber is sealed can affect the results; too short and low emission rates cannot be measured; too long and the N_2O could be so concentrated that it causes a feedback effect slowing the rate of N_2O emitted. If feedback occurs, then the pattern of emission becomes non-linear and a single end-of-chamber-sealed sample will not give an accurate measure of the N_2O flux. We typically use a 60 minute closure time.

Gas emissions are also known to vary with the time of day they are made, principally due to changes in the soil temperature affecting the rates of the soil processes contributing to the N_2O release. Previous research has often found that, when significant N_2O emissions are occurring, maximum fluxes are in the afternoon and minimum fluxes in the early morning – provided soil water content is constant. Manual chamber measurements are therefore typically made in the late morning when the flux rate should approximate the average rate for a whole 24-hour period.

In an irrigated cotton soil, conditions of soil water content and mineral nitrogen (N) content (from pre-plant and water-run fertiliser) vary tremendously, so the sampling chamber locations are important to get an accurate 'average' flux for the plot as a whole. Since every second furrow is irrigated, there is a two metre cross-section of different soil conditions that is repeated across the field. We typically use four manual chambers of 15 cm diameter with two in the furrows, and one on either side of the plant bed.

In 2015, we conducted three intensive gas sampling experiments to explore the assumptions used in our regular N_2O emissions sampling. These campaigns examined;

1. the variation in N_2O emissions in relation to chamber closure time
2. the variation in N_2O emissions over a full 24-hour period
3. the variation in N_2O across a two metre cross section of hills and furrows within a cotton crop.

Site details

Location	'Ruvigne', Gunnedah
Co-operator	Rod Smith
Soil type	Black vertosol (medium clay). Soil (0–30 cm) texture was 65% clay, 9% sand and 26% silt.

Rainfall and irrigation	These investigations occurred in a single week following the second irrigation (water-run urea applied). There was no rainfall during this week.
Sowing date	The site was sown with Sicot 74BRF on 1 October 2015.
Harvesting date	The trial was picked on 8 May 2016.

Trial designs

1. **Chamber closure time**: N_2O concentrations in air samples were collected from four different chambers at 15-minute intervals for a total of 90 minutes.
2. **Time of day of measurement**: a semi-automated sampling system was used to measure N_2O flux in four different chambers (two chambers each in two treatments) every three hours over a 24-hour period. The samples were collected starting on the second day after the second irrigation. These chambers were 50 cm × 50 cm × 15 cm and were situated directly over the plant bed. On lid closure, air samples were collected at 0, 30 and 60 minutes. Treatment 1 (T1) had 30 kg N/ha applied as water-run urea during the irrigation, while T3 was irrigated with water only.
3. **Sampling location:** Immediately following the second irrigation, 12 manual chambers (15 cm diameter × 15 cm high) were situated in a two-metre-long transect perpendicular to plant rows. Air samples were collected from each chamber both before and 60 minutes after being sealed with an airtight lid. Daily N_2O flux was calculated by the rate of increase in N_2O concentration with closure time, averaged over 24 hours. Sampling occurred at 1, 2, 4 and 7 days after the irrigation event. We compared the average N_2O flux results gained using the usual four chamber positions against the average from the 12 chambers covering all possible hill and furrow positions. Soil water content was measured from each position at each gas sampling time. Surface soil (0–10 cm) mineral N was also measured from all 12 positions before the irrigation, and again after the gas sampling experiment concluded. This trial was unreplicated.

The site had 160 kg N/ha applied as anhydrous ammonia pre-plant to the non-irrigated side of the plant bed. These measurements were made in the week following the first of two in-crop applications of 30 kg N/ha applied as water-run urea in the second and third irrigations. The pre-plant N fertiliser was applied on 16 September 2015.

Results

Chamber closure time

Nitrous oxide emission rates varied greatly between the four chambers, but the increases in N_2O concentration with closure time were essentially linear for at least 60 minutes in three of the four chambers (Figure 1). The rate of N_2O concentration increase with time in these three chambers became non-linear for closure times greater than 60 minutes, so longer times are not advised when emissions are quite high, as at this sampling time. The other chamber in the four tested had a much lower flux, but also showed an unusual pattern of N_2O concentration with time. After an initial increase in N_2O concentration between 0 minutes and 30 minutes, the N_2O concentration then remained stable until 75 minutes, after which it also declined.

Time of day of measurement

There was significant N_2O emission activity from T1, but much less from T3 during the first few days after the second irrigation, as T1 was irrigated with water-run urea (Figure 2). There appears to be a trend in N_2O emissions that roughly follows soil temperature (albeit with a lag of several hours). However, while N_2O flux varied with time in T3, the apparent trend for T1 was not significant due to the large variation between replicate chamber results. The dotted lines in Figure 2 indicate the mean flux for each treatment. Compared with the average of the eight measurements over a 24-hour period, taking a single daily measurement at 9 am would have underestimated the daily average by 31%. This data is from one single day and might not represent the diurnal flux patterns occurring on other sampling days throughout the season.

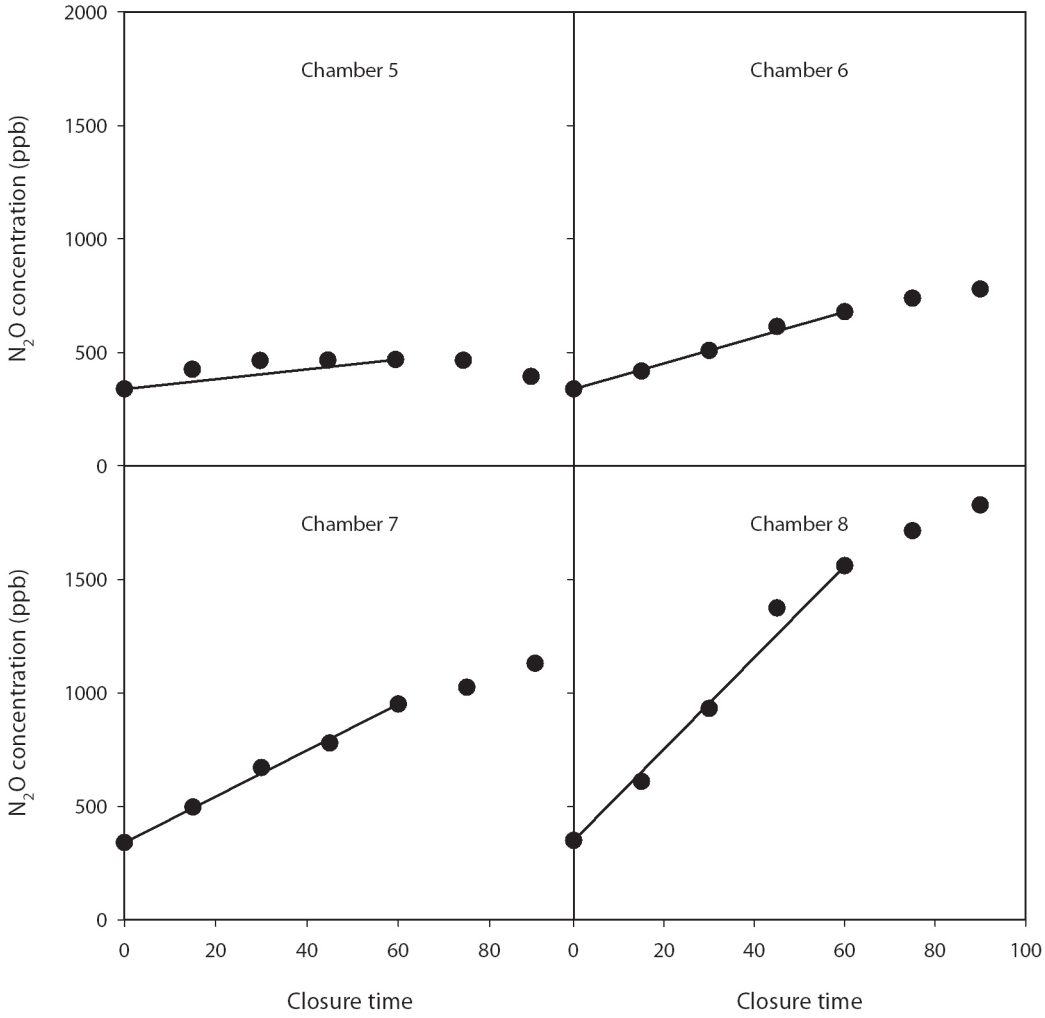

Figure 1. Change in N_2O concentration with chamber closure time in four individual chambers measured on the second day after the end of the second irrigation with water-run urea. Lines indicate the 0–60 minute linear relationship used to calculate fluxes for all other manual chamber measurements.

Chamber location

Before the irrigation event (day one), soil moisture content was very low in the surface and soil nitrate was unevenly concentrated in the top 10 cm of the soil, with high concentrations associated with/near the location of the pre-plant gaseous ammonia injections on either side of the non-irrigated furrow (Figure 3, top). After irrigation, the water content was initially high and even across all but the plant row positions, which were drier. Over the week-long experiment period, the moisture content stayed wetter in the mid-furrow positions.

The soil sampling done nine days after the irrigation showed significant changes in nitrate N distribution within the cross section, with increased nitrate concentrations associated with the pre-plant fertiliser bands, but also increased nitrate found on the sides of the irrigated furrow (from the water-run N). A large increase in soil nitrate under the first plant row is not easily explained and does not match the more modest increase under the second plant row position (Figure 3, middle).

Nitrous oxide fluxes in most positions increased in response to the changes in soil moisture and soil nitrate concentration caused by the irrigation event (Figure 3, bottom). One day after the irrigation concluded, N_2O flux was greatest on the sides of the irrigated furrow and also the hillsides adjoining the irrigated furrow. Fluxes in these areas increased further by day two. The sides of the non-irrigated furrow also showed increased emissions on day two. Conversely, on day four, emissions had subsided on the sides of the irrigated furrow, but increased in the irrigated furrow position. By day seven, all N_2O fluxes had returned to a low baseline (Figure 3, bottom).

The average flux from all 12 chambers on each day of measurement was approximately equal to the average of the four chambers normally used for the routine sampling. In terms of calculating cumulative N_2O emitted, there was little difference between four- and 12-chamber calculations, thus supporting our choice of the positions for the four chambers.

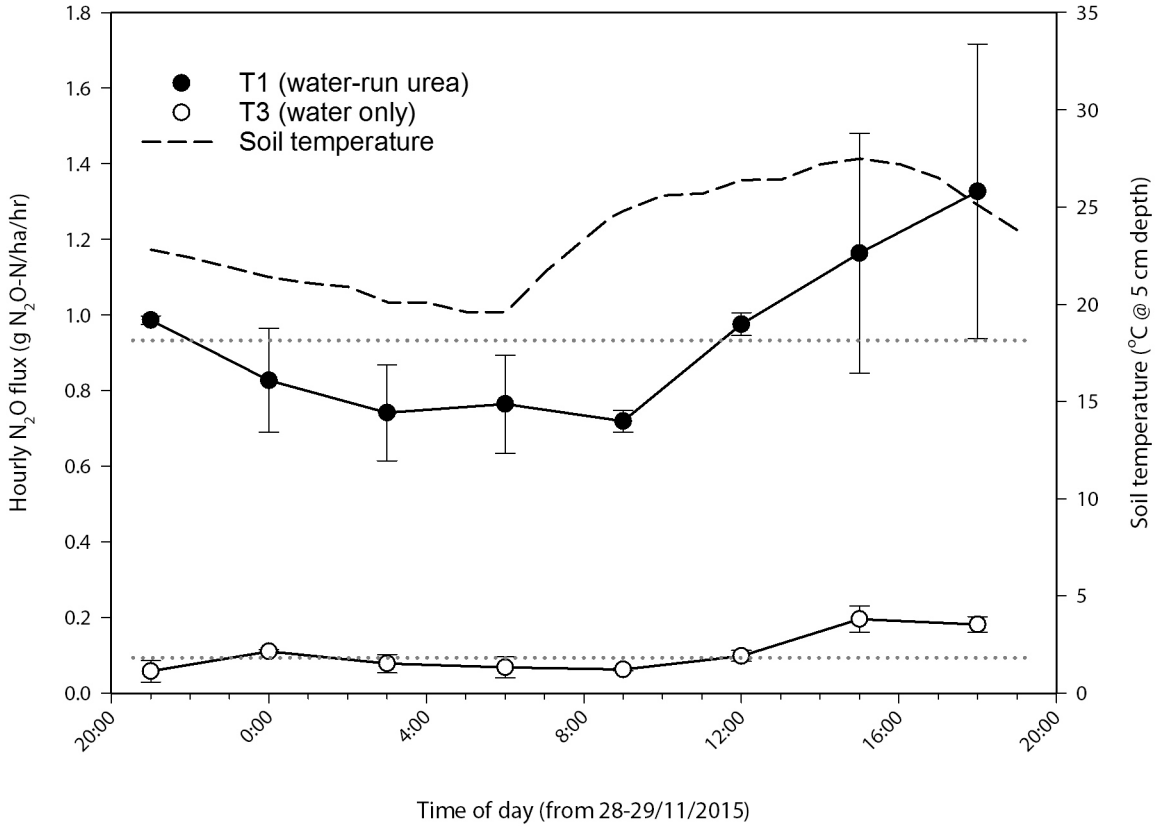

Figure 2. The influence of time-of-day of sampling on hourly N_2O flux on the second day following the second irrigation (with water-run urea in T1) – Gunnedah 2015. The dotted lines indicate the daily average of all measurement times for the two treatments. Soil temperature is shown as a dashed line in relation to right-hand axis.

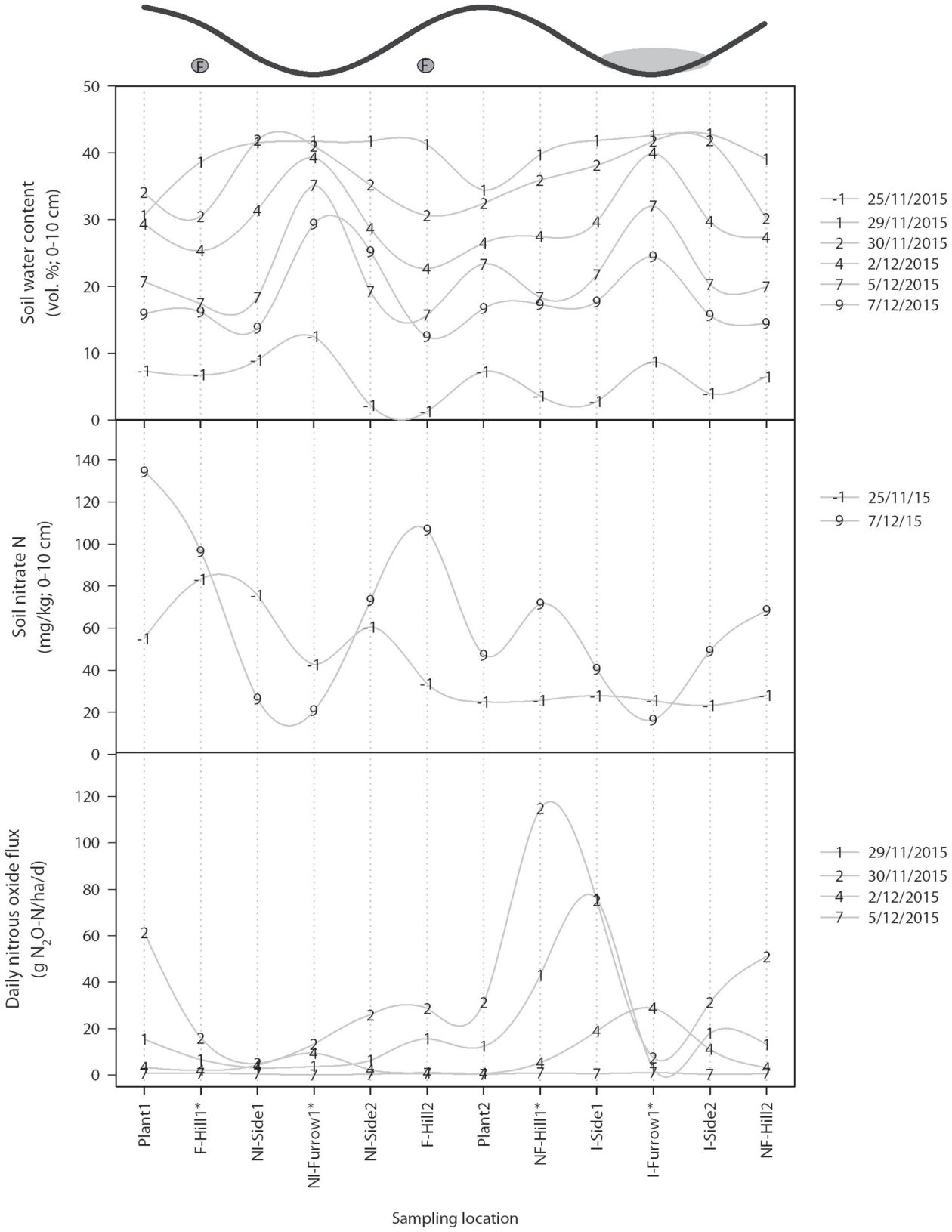

Figure 3. The influence of sampling position within the two metre wide cross-section on surface soil moisture [top], soil nitrate [middle], and daily nitrous oxide flux [bottom] following the second irrigation (with water-run urea) – Gunnedah 2015. Grey circles (above the graph) indicate the position of the pre-plant anhydrous ammonia. The shaded furrow indicates the irrigated furrow. Symbols on graphs indicate the number of days after irrigation. Positions named with * indicate the 4 typical chamber positions.

Conclusions

These three experiments were used to test some of the assumptions related to the techniques used in our regular N_2O sampling using manual chambers in irrigated cotton fields.

In the first test, we found that the assumption of a linear N_2O emission rate over the 60 minute chamber closure time that we commonly use was valid, so no changes were made to this part of the procedure. Shorter times would also have been valid for regular sampling, but shorter times also create time issues when large numbers of chambers are being sampled together across a large trial site.

In the second test, we found that N_2O flux as measured at our usual sampling time (starting 9:00–9:30 am) appeared to be underestimating the daily average amount, although the treatment with the higher N_2O flux rate (T1) showed no significant effect from time of day. Nevertheless, since the results suggested that sampling later in the morning would give a better approximation of the average daily N_2O flux, we modified our sampling in the following season to begin later (10:00–10:30 am).

The third test confirmed that our choice of four chamber locations within a two-metre-wide cross-section of the irrigated cotton field gave a good approximation of the N_2O emissions from the whole of plot area, so no changes were made to the routine procedure.

Acknowledgements

These experiments were part of the project *Determining optimum nitrogen strategies for abatement of emissions for different irrigated cotton systems* (AOTG14013; 2013–17), with joint investment by NSW DPI and DAWR, and administered by CRDC.

Thanks to Rod Smith for providing the experimental sites and for applying the N fertiliser treatments into the required plots. Thanks to Mandy Holland for assistance in field sampling. All soil and plant N analyses were carried out by Clarence Mercer, NSW DPI at the ISO9001-accredited laboratory at Tamworth Agricultural Institute, NSW DPI.