Factors driving nitrous oxide emissions from uncropped (head ditch and tail drain) areas of irrigated cotton fields after water-run urea application

Graeme Schwenke[1], Gunasekhar Nachimuthu[2], Clarence Mercer[1] and Annabelle McPherson[1]
[1]NSW DPI, Tamworth, [2]NSW DPI, Narrabri

Key findings

- A soil and sediment survey of 10 irrigated cotton paddocks across four cotton-growing valleys revealed the tail drain sediments were enriched in organic carbon (1.03% ± 0.05) and nitrogen (0.11% ± 0.01) compared with head ditch soils (0.73% ± 0.07 for carbon and 0.08% ± 0.01 for nitrogen) of the same paddocks. Nitrate-nitrogen and dissolved organic carbon analyses showed similar trends.
- After irrigation, tail drain samples tended to release more nitrous oxide compared with head ditch samples. Emission rates were linked to the pre-irrigation mineral nitrogen concentrations of the soil/sediments.
- These non-cropped areas, representing up to 2% of the paddock area, are a significant source of nitrous oxide emission per unit area of farm as they retain high soil moisture and nutrient concentrations in the absence of plants.
- Nitrous oxide emission calculations for cotton farming systems should incorporate the emissions from head ditch and tail drain sections of the irrigation network.

Introduction

Agricultural intensification has led to large scale, off-farm environmental impacts (Drinkwater & Snapp, 2007). One of the direct effects is on the global nitrogen (N) cycle and synthesis of nitrous oxide (N_2O) from reactive N in the soil. Land management practices, in conjunction with climate, fertiliser and water management practices, can significantly affect N_2O emissions from agricultural soils. Consequently, research to quantify the N_2O fluxes from various cropping systems, including cotton, has attracted great attention (Grace, 2016). Previous research on N_2O emissions has focused on cotton farm cropping zones and indirect emissions from irrigation water (Macdonald, Rochester & Nadelko 2015; Grace et al., 2016). The non-cropped areas in irrigated cotton farms can account for approximately 2% of the paddock area. The fertiliser N applied or leached into these zones can contribute to higher levels of mineral N than in the cropping field where growing plants deplete the applied N. The potential contribution from uncropped zones (head ditch and tail drain) to overall N_2O emissions in irrigated cotton production systems in Australia has not yet been quantified. In this laboratory study, we have simulated the irrigation and water-run urea application in soil and sediments to determine the N_2O emissions from the uncropped zones of cotton farms.

Site details

Location	Soil and sediment samples were collected from 10 cotton farms across four cotton-growing valleys (Namoi, Gwydir and Macquarie in NSW, and Central Highlands in QLD).
Soil properties	Table 1 details the sediment sample soil properties collected from cotton farms to be used in the simulation study.

Trial design

A soil incubation experiment was conducted whereby incubation chambers (150 mm diameter × 150 mm height) were filled with 2 kg of dried, ground, soil/sediment (<5 mm), allowing enough space for water to be applied. Treatments consisted of 10 farms × 2 locations (head ditch, tail drain) × 2 irrigation water treatments (water only, water-run urea) × 4 reps = 160 chambers. For the added-urea treatments, 5 kg N/ha was added to the tail drain samples and 30 kg N/ha added to the head ditch samples. This was to simulate a typical water-run urea application in the field. Both water only and water-run urea treatments included 10 mg/L of dissolved organic carbon (DOC), applied as glucose, to simulate the DOC typically found in irrigation water. All chambers were set up in an airconditioned room set to 25 °C. After the water was added, chambers were periodically capped with lids (1, 2, 4, 7, 14 days after water added) and fluxes of nitrous oxide were measured by manual gas sampling through a rubber septum in the lid, followed by gas chromatographic analysis. Lids were removed after sampling, allowing the soils to dry during the incubation period. On day 14, all soils were again wet up, this time to 100% water holding capacity. For the next 10 days, chambers were sampled for gaseous fluxes at the same time intervals as before (i.e. days 1, 2, 4 and 7 after water application). All soils were soil cored at the conclusion of the trial on day 25 and analysed for water content by oven drying at 105 °C, and mineral N by extraction with 1M KCl solution and subsequent colorimetric analysis using a flow injection analyser.

Table 1. Soil properties of the sediment samples collected for the incubation study.

Location	Farm**	Site*	%C	%N	C/N	DOC (mg/kg)	Nitrate (mg N/kg)	Ammonium (mg N/kg)	Water holding capacity (g/g)
Narrabri	An	HD	0.48	0.06	8.6	17	21	1	0.50
Narrabri	An	TD	1.07	0.12	8.9	46	65	7	0.59
Warren	Aw	HD	0.74	0.09	8.6	16	21	1	0.35
Warren	Aw	TD	1.19	0.11	10.6	67	47	3	0.40
Burren Junction	Bw	HD	0.55	0.07	8.2	32	43	2	0.49
Burren Junction	Bw	TD	0.81	0.10	8.2	82	136	2	0.50
Emerald	Em	HD	0.69	0.07	10.3	18	15	1	0.30
Emerald	Em	TD	0.74	0.07	10.1	52	19	2	0.35
Narrabri	Ff	HD	0.65	0.08	8.1	24	38	1	0.46
Narrabri	Ff	TD	0.95	0.12	8.1	69	37	2	0.50
Wee Waa	Gl	HD	0.70	0.08	8.8	9	58	1	0.45
Wee Waa	Gl	TD	1.08	0.13	8.5	105	22	14	0.46
Gunnedah	Gu	HD	1.26	0.12	10.8	25	29	3	0.44
Gunnedah	Gu	TD	1.25	0.12	10.6	63	101	2	0.53
Narromine	Nh	HD	0.78	0.10	7.8	43	53	3	0.37
Narromine	Nh	TD	0.98	0.14	7.3	65	64	96	0.41
Moree	Rb	HD	0.74	0.07	9.8	15	48	2	0.38
Moree	Rb	TD	1.11	0.12	9.4	86	141	4	0.43
Narrabri	Wn	HD	0.75	0.09	8.1	26	41	2	0.34
Narrabri	Wn	TD	1.10	0.11	9.8	62	11	3	0.44

*HD = head ditch; TD = tail drain; **See Farm locations below for abbreviation key

Treatments

Farm locations (10)	Narromine (Nh), Narrabri (An, Ff, Wn), Warren (Aw), Burren Junction (Bw), Wee Waa (Gl), Moree (Rb), Emerald (Em)
Location (2)	Head ditch (HD), tail drain (TD)
Irrigation water (2)	Water only, water-run urea (30 kg N/ha applied to head ditch soils, 5 kg N/ha applied to tail drain samples). All samples also had 10 mg C/L applied as glucose dissolved in the applied solutions.

Results

Nitrous oxide emissions as influenced by irrigation and water-run application

Daily fluxes (Figure 1) were combined to give cumulative totals of N_2O emitted for each sample during the study (Table 2). Statistical analysis of the whole dataset together showed significant differences ($P<0.05$) according to farm, sample location, solution used, and all interactions between these factors, except for the farm × location × solution interaction.

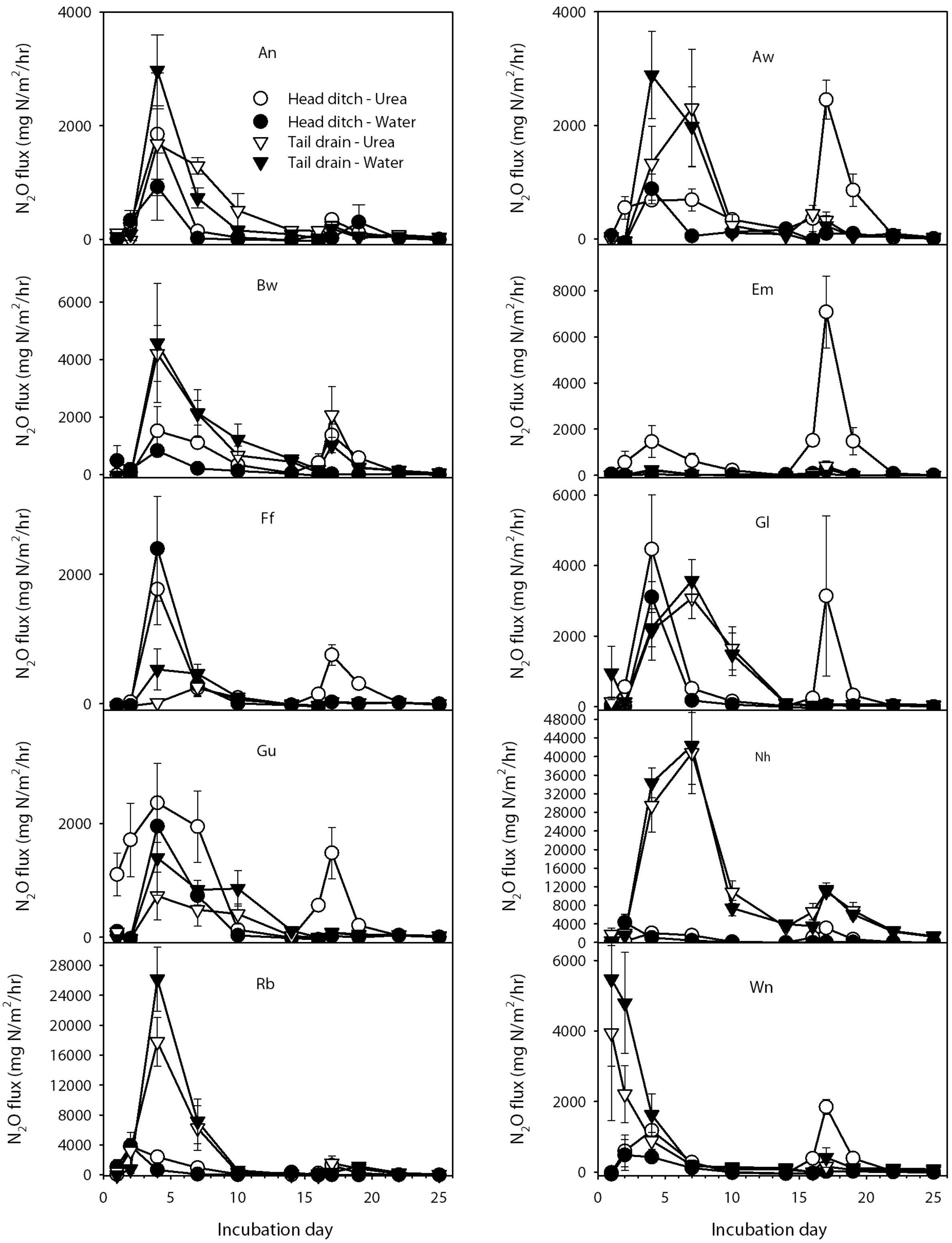

Figure 1. Daily mean nitrous oxide flux for head ditch and tail drain samples of 10 commercial paddocks during incubation with either added water or dissolved urea solution. Each point is a mean of four replicate chambers ± standard error. Note different scales used for each paddock.

In general, the adding urea solution increased fluxes in head ditch samples by between 111–2578% (median increase = 250%), while adding a less concentrated urea solution to tail drain samples had no overall effect. Separate statistical tests on each sample showed that the solution used (water or water-run urea) mostly affected N_2O loss from samples with low initial mineral N concentrations. In all but one case (Ff-tail), there was significantly more N_2O emitted from the treatment with water-run urea solution added compared with water added. It can be seen from Figure 1 that most of the difference occurred during the second simulated irrigation event, as fluxes during the first event were more similar between water and urea solution treatments.

Table 2. Cumulative nitrous oxide (mg N_2O-N/m^2) emitted during incubation according to farm, sample location (head ditch, tail drain), and solution (water, urea). Significant ($P<0.05$) solution effects are indicated by different letters for each pair.

Farm	Head ditch		Tail drain	
	Urea	Water	Urea	Water
An	126	66	250	230
Aw	261[b]	79[a]	287	312
Bw	271	85	522	572
Em	464[b]	18[a]	24[b]	7[a]
Ff	147	132	22[a]	63[b]
Gl	383[b]	167[a]	472	518
Gu	405[b]	150[a]	110	207
Nh	386[b]	189[a]	6715	6635
Rb	339	188	1516	1925
Wn	168[b]	34[a]	232	386

Conclusions

Tail drain samples tended to release more nitrous oxide compared with head ditch samples, with fluxes linked to initial mineral-N concentrations of soil/sediments before the irrigation or water-run urea additions. These non-cropped areas within the farm might be the highest source of N_2O emission per unit area of the paddock as they tend to retain high levels of moisture and nutrients in the soil, especially in the tail drains.

The results suggest that emissions occurring in uncropped head ditch and tail drain soils are mainly influenced by interactions between irrigation and fertiliser management practices, and baseline nitrogen concentrations. In future research, the quantum of these emissions needs to be compared simultaneously with N_2O emissions from cropped areas under field conditions.

References

Drinkwater LE & Snapp SS (2007). Nutrients in agroecosystems: rethinking the management paradigm. *Advances in Agronomy* 92: 163–196.

Grace P (2016). Foreword. *Soil Research* 54: i–ii.

Grace P, Shcherbak I, Macdonald B, Scheer C & Rowlings D (2016). Emission factors for estimating fertiliser-induced nitrous oxide emissions from clay soils in Australia's irrigated cotton industry. *Soil Research* 54: 598–603.

Macdonald BCT, Rochester IJ & Nadelko A (2015). High yielding cotton produced without excessive nitrous oxide emissions. *Agronomy Journal* 107.

Acknowledgements

Investment by DAWR, CRDC and NSW DPI is gratefully acknowledged. We acknowledge the growers and farm managers for their co-operation and permission to collect the samples for the simulation study. Technical assistance from Amanda Noone (Emerald), Lloyd Finlay, Mark Watkins and Wayne McPherson is gratefully acknowledged.