NITROGEN LOSSES FROM SOIL AND IRRIGATION WATER

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Our Fibre. Our Focus. Our Future

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Summary

Several recent experiments at ACRI, Narrabri have illustrated the fate of N fertiliser in irrigated cotton cropping. During the cotton growing season of 2011-2012, nitrous oxide (N_2O) emissions totalled 0.51, 0.95, 0.78 and 10.62 kg N_2O /ha, for the four N fertiliser rates (0, 120, 200, or 320 kg N/ha). Further measurements have indicated that about 12 kg N/ha was lost to deep drainage and 10-15 kg N/ha was lost in the tail water following irrigation. Shallow fertiliser placement resulted in N moving out of the hills and lost via denitrification in the irrigation network.

Introduction

Cotton is a high value commodity and crops normally require N fertiliser to optimise lint production. Growers cannot afford to under-fertilize with N (or other nutrients) and tend to manage risk by ensuring their cotton crop yields are not limited by N deficiency. Cotton-growing soils are typically medium to heavy clays and are prone to waterlogging following furrow irrigation or heavy rain (Scheer et al., 2008, Scheer et al., 2013, Han et al., 2014). Losses of 50-100 kg N/ha can occur during the growth of a cotton crop through denitrification and leaching (Rochester 2003), resulting in inefficient use of N fertiliser. Periodic waterlogging and drying drives soil the denitrification processes which leads to the production of nitrous oxide (N_2O) and nitrogen (N_2) gases. Measured losses from the fertilised hills in furrow irrigated systems are typically below 3% of the applied fertiliser (Rochester 2003, Mahmood et al. 2008, Scheer et al. 2013). In cotton production systems emissions of N_2O from the furrows can be greater than the hills when urea is water-run down the furrows (Grace et al., 2010). Grace et al (2010) also indicated there was substantial movement of nitrate-N from the mounds into the furrows. In furrow systems which are over-irrigated, up to 18.6 kg N/ha can be lost into the irrigation network (McHugh et al., 2008).Once the nitrate enters the tail water it is lost from the field and may undergo denitrification to N_2O and N_2 in water storages. Harrison and Matson (2003) have shown in furrow irrigated wheat production in Mexico that N_2O losses can be large, averaging 40 N_2O-N g/ha/day. This paper seeks to identify key nitrogen loss pathways in Australian cotton production systems.

Methods

Land surface N_2O Measurements and N_2 estimate

Emissions from the soil and crop were measured using chambers (see Scheer et al. 2013) connected to a fully automated system that enabled N_2O emissions from each of the four fertiliser treatments. The N_2O concentrations were measured with gas chromatography. N_2O was measured during all phases of a 2-year cotton-faba bean-fallow rotation. N_2 emission was estimate from the N_2O:N_2 mole relationship determined by Rochester (2003).

Dissolved nitrate, organic nitrogen and nitrous oxide in the irrigation network

Filtered (0.45 µm) water samples were collected for the determination of nitrate, total ammonia nitrogen (TAN), and total dissolved nitrogen (TDN). Total nitrogen (TN) was determined on unfiltered samples. Collected samples were placed in an insulated box and stored at 4oC, returned and analysed in the laboratory within 7 days. Nitrate and TAN were measured using the cadmium reduction method (Method 4500 Nitrate F;Rice et al., 2012) and automated phenate method (Method 4500 Ammonia G; Rice et al., 2012). The TN and TDN samples were digested using the persulphate method (Method 4500-N; Rice et al., 2012) and the nitrate concentration in the digest was measured using the cadmium reduction method. Dissolved nitrous oxide concentration was determined using the headspace equilibrium technique (Weiss and Price, 1980).

Estimations of N_2O flux

Nitrous oxide flux was estimated from dissolved nitrous oxide concentrations using the following equation:

$$flux = k_{total} * \left(N2O_{(water)} - N2O_{(eq)}\right)$$

Where $N_2O_{(water)}$ is the measured concentration of N_2O in the water, $N_2O_{(eq)}$ is the concentration the water would have if it were in equilibrium with the atmosphere and k is the gas transfer coefficient ($m.s^{-1}$) (Clough et al., 2007; Cole & Caraco, 2001).

The gas transfer coefficient, k_{total}, was calculated as the sum of the transfer velocities attribute to wind (k_{wind}) and water (k_{water}) speed; and were calculated using the following equations (Clough et al., 2007; Wanninkhof, 1992).

$$k_{wind} = 0.31u_{10}{}^2\left(\frac{Sc}{660}\right)^{0.5} \text{ and } k_{water} = \sqrt{\frac{DU}{h}}$$

where u_{10} = the windspeed at 10m above the height of the water body, Sc is the Schmidt number for N_2O, D is the diffusion coefficient of N_2O in water, U is the velocity of water ($m.s^{-1}$) and h is the average depth of the water body (m). Where water speed was unavailable, k_{wind} was used instead of k_{total}.

The wind speed at 10m height was calculated using the logarithmic wind profile law:

$$\frac{U_1}{U_2} = ln\left(\frac{Z_1}{Z_2}\right) \div ln\left(\frac{Z_2}{Z_0}\right)$$

where Z_0 is the 'effective roughness height', here assumed to be 0.001m, and U_1 and U_2 are the respective wind speeds at heights Z_1 and Z_2, respectively (Kubik et al., 2011). Sc and D were calculated in R, using the package 'marelac' (Soeraert et al., 2010; R Core Team, 2014).

TABLE 1. The flux of nitrate and DON+TAN from each field and its potential contribution to N_2O emissions (per irrigation per ha).

	Nitrate Pool		DON+TAN Pool	
Irrigation Network Component	kg N	g N_2O-N#	kg N	g N_2O-N!
Tail Drain D4	1.1 (0.9)*	102 (87)*	2.7 (5.8)	80 (23)
Return	0.4 (0.0)*	34 (0)*	2.8 (56.1)	85 (224)
Tail Drain F3	2.4*	215(NA)*	7.9	711 (NA)
Tail Drain F7	2.3*	206 (NA)*	1.8	157(NA)
Storage	108 (0.7)^	5771 (4649)^	73	1290 (NA)

#Conversion from NO_3 to N_2O based on Seitzinger and Kroeze 1998 method ;!
Conversion from DON based on Kyoto Protocol estimates for waste water;
*Assuming 1 ML/ha irrigation at 75% efficiency; ^Assuming 33 ML irrigation water in storage

Measurements of deep drainage loss of nitrogen

Water samples were analysed for dissolved N from the drainage lysimeter at the ACRI and used to estimate nitrogen loss from the upper profile.

Results and Discussion

Nitrous oxide emissions from the land surface

Overall for the 0, 120 and 200 kg N /ha fertiliser applications, 40-50% of the N_2O was emitted from the cotton phase, 5-10% from the faba bean phase and 30% from the fallow. For the over-fertilised 320 kg N/ha treatment, 80% of the N_2O was emitted from the cotton phase, 6% from the faba bean phase and 14% from the fallow. The N_2O-N emission factor corrected for the background for the 320 kg N/ha treatment was 3.2% compared with <0.9 % for the other measured rates It is evident that during the measurement period that to minimise N_2O production and maintain yield the fertiliser rate should not have exceeded 200 kg N/ha.

Dissolved nitrate, organic nitrogen and nitrous oxide in the irrigation network

The water chemistry of the irrigation waters shows that the DON+TAN fraction is as large as the NOx fraction (Table 1) and should be considered for nitrogen budgeting. Further, it was observed that there was significant variation in the water nitrogen concentration during irrigation and between irrigations. The soil physical and moisture characteristics also vary within each row and hill and as a result the irrigation water and dissolved nitrogen compounds will transit through the soil at different rates.

The NOx and DON+TAN concentration in the water increases during its transit down the field. The NOx and DON+TAN appear to be sourced from the adjacent hill and are collected as the irrigation water seeps through into the next furrow. It was observed during one irrigation that the irrigation furrow was less saline than the non-irrigated furrow. This indicates that irrigation water is removing salts from the furrow and adjacent hills and transporting them into the tail drain and return channel. As expected, concentrations of N_2O within the irrigation network were small in comparison to other forms of N, with concentrations ranging from 162ng/L to 6530ng/L (e.g. Cole & Caraco, 2001; Harrison & Matson, 2003). Throughout the sampling period, flux of N_2O from the irrigation network ranged from 9.76 to 7795.90 g N_2O-N ha^{-1} d^{-1}, averaging 222.54 g N_2O-N $ha^{-1}.d^{-1}$.

Deep drainage loss of nitrogen

During the 2008-2009 cotton season we measured nitrogen leaching from the surface down to 2 meters depth. About 10 kg of N/ha was lost by deep drainage during that cotton season which equated to 6% of the applied fertiliser (160 kg N/ha).

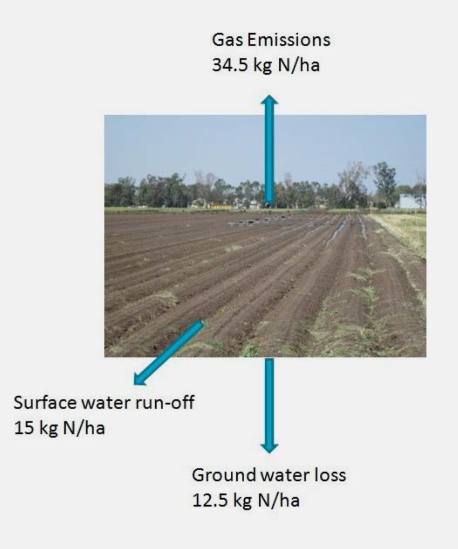

FIGURE 1. Partitioning the estimated nitrogen losses from the application of 200 kg N/ha. The remainder is either stored in the soil or was consumed by plant and soil microbial uptake.

Conclusions

Our measurements estimate that ~40% of the applied urea-N was lost from the field (Figure 1) into the atmosphere and into the subsoil and removed in run-off irrigation water, including water storages. The surface water and nitrogen gas components represent the greatest loss pathways. In the systems we studied, urea was drilled into the hill to a depth of 20 cm prior to sowing and irrigation was applied to alternate furrows that resulted in N leaching from the hills. It is evident that N_2O emissions from the tail water can increase the GHG footprint of the irrigated system. Mitigation strategies include reducing irrigation volumes, placing the N fertiliser deeper in the soil, and strategically use N-rich tail water in adjacent fields.

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