Nitrous oxide emissions from irrigated cotton soils of northern Australia

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Abstract
An automated gas sampling methodology has been used to estimate nitrous oxide (N_2O) emissions from heavy black clay soil in northern Australia where split applications of urea were applied to furrow irrigated cotton. Nitrous oxide emissions from the beds were 643 g N/ha over the 188 day measurement period (after planting), whilst the N_2O emissions from the furrows were significantly higher at 967 g N/ha. The DNDC model was used to develop a full season simulation of N_2O and N_2 emissions. Seasonal N_2O emissions were equivalent to 0.83% of applied N, with total gaseous N losses (excluding NH_3) estimated to be 16% of the applied N.

Key Words
Nitrous oxide, cotton, DNDC, nitrogen.

Introduction
Cotton is one of many agricultural industries heavily reliant on nitrogenous fertilizers and water storages to maintain high levels of production. Irrigated cotton farming systems have been labelled as potentially high-risk agricultural systems with respect to gaseous losses of nitrogen to the atmosphere with the inefficient use of fertiliser applied N also reducing profitability. Irrigated cotton grown on alkaline grey clay soils often use nitrogen fertilizer inefficiently, due largely to nitrogen loss (commonly 50 - 100 kg N/ha) through denitrification. These and the heavier black clays (Vertisols) are the dominant soils in the cotton growing region of Australia and with their high water holding capacity are ideal environments for denitrification and associated losses of nitrous oxide (N_2O) and N_2. The nitrogen gases emitted also include ammonia, but it is N_2O, a potent greenhouse gas with a Global Warming Potential (GWP) approximately 300 times that of carbon dioxide (CO_2), which has fuelled debate. Rochester (2003) has estimated that just over 1% of applied N is emitted as N_2O from alkaline grey clay soils in a cotton system. There is much speculation about the actual contribution of cotton cropping systems to global warming, a secondary objective of this study. The Intergovernmental Panel for Climate Change (IPCC, 2006) prescribe 1% of applied fertilizer N as a general figure to estimate direct N_2O emissions from fertiliser application. The only reported direct measurements of N_2O emissions from cotton soils in Australia were obtained from a 10 weeks during the 2002-03 season by Grace *et al.* (2003) using a simple manual chamber technique and these ranged from 0.2-1.53% of applied N. This study details both field experimentation and simulations to derive more reliable estimates of nitrogen losses, specifically N_2O emissions from N fertilizer applied to cotton growing soils, with the potential for identifying management strategies for reducing total N losses, increasing nitrogen use efficiency and profitability.

Methods
Site management
The furrow irrigated cotton field was located on the Crothers farm near Dalby, Queensland. The field had been under continuous cotton (with winter fallow) for 10 years. The block has a long history of conventional tillage, with a spraying regime typical for cotton production in this area. Bollgard varieties are typically used. The black clay (clay 68%) is typical of the region with an average soil organic carbon content in the top 10 cm of 1.0% and a pH of 8.5. Urea was banded on 10 and 30 August, 2005, at 92 and 70 kg N/ha, respectively. Cotton was sown on 2 November, with 30 kg N/ha NH_3 applied with irrigation water on 26 January, 2006, and an additional 15 kg N/ha water run urea applied on 24 February. A total of 207 kg N/ha was applied during the season, with post-sowing irrigation events restricted to a single occasion (24 February, 2006) due to fact the farm received exceptional rainfall during the season.

Equipment
Soil emissions of carbon dioxide (CO_2), methane (CH_4) and N_2O during the 2005/06 (August-March) growing season were estimated using a fully automated gas sampling and analysis system. The automated system used in this project is a modified design of closed chamber technique originally described by Butterbach-Bahl *et al.* (1997) and allows for data collection and analysis on a two hour cycle. Briefly, the measuring system consists of a gas chromatograph (SRI GC8610) equipped with a 63Ni electron capture detector (ECD) for N_2O analysis and flame ionization detector (FID) for CH_4 analysis, a LICOR Infrared gas analyzer (IRGA) for CO_2, a gas sampling system, a compressor, six measuring chambers and computer for operating software and data storage.

To meet the demand for portability, the system is entirely contained in two steel boxes. The square aluminium chambers have transparent acrylic panes, and cover 2500 cm^2. The chambers have an internal temperature sensor, with 55^oC set as the threshold for opening to avoid any heat damage to plants. Transparent extensions can be fitted to increase the height of the chambers to 75 cm and 100 cm, to accommodate actively growing plants. Three chambers were assigned to a single bed and placed five metres apart, and three to an adjacent furrow after skipping two rows. Gas sampling was confined to the period 9 October, 2005 to 23 March, 2006. Soil samples (0-10 cm) were periodically removed for nitrate analysis. Yield samples were also taken at harvest.

Simulation
The DNDC model version 8.9 (Li *et al.* 1996) was used to test the viability of a simulation approach to mimic N_2O emissions from irrigated cotton soils of northern Australia and to estimate emissions at the beginning of season as N fertiliser had been applied in early August, well before planting and deployment of the automatic chambers. The crop production aspect of the model had been calibrated with data collected the previous year before at Narrabri, NSW. The only difference was the use of location specific input variables for soil properties, climate and crop management for the Crothers farm. The internal parameters of the model relating to soil carbon, nitrogen and water cycles remained the same as distributed with the model.

Results
The daily emissions of N_2O from 69-257 days after the initial fertiliser application are presented in Figure 1. Note the incidence of rainfall and irrigation events (arrowed) which resulted in the surface soil being saturated, and the corresponding increase in emissions at 108, 144 and 170 days after fertiliser (DAF) application. Soil nitrate (0-10 cm) declined from 77 to 27 kg N/ha from 83 to 153 DAF.

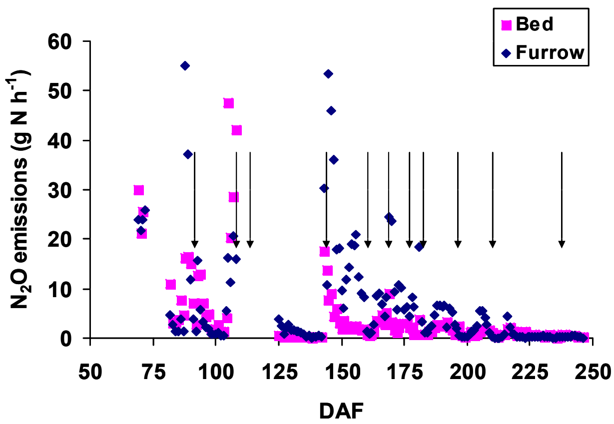

Figure 1. N_2O emissions from a black clay at Dalby, Queensland (2005/06) fertilised with a split application of 207 kg N (DAF – Days after fertiliser applied; arrows indicate rainfall and irrigation events which have restored the surface soil to saturation).

Nitrous oxide emissions from the beds were 643 g N/ha during the measurement period of 188 days (with 14 days lost as downtime) whilst the N_2O emissions from the furrows were significantly higher at 967 g N/ha. This observation confirms the leakage of nitrate from beds to furrows and the higher potential for emissions where soils were saturated for longer periods for time. The observed values for N_2O emissions depicted in Figure 2 are the mean value of the observations for the bed and furrow chambers.

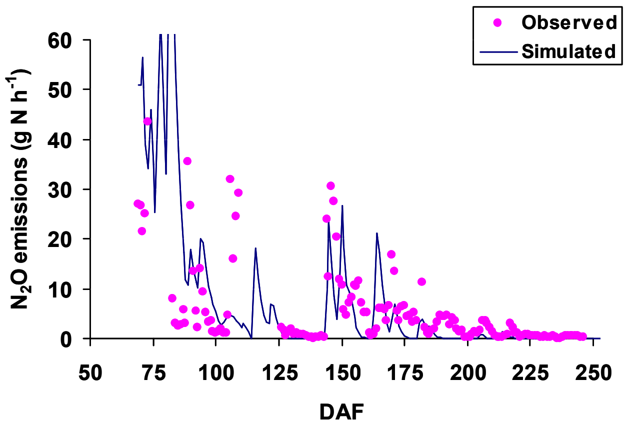

Figure 2. Simulated and observed N_2O emissions from a black clay at Dalby, Queensland (2005/06) fertilised with a split application of 207 kg N (DAF – Days After Fertiliser applied).

The reliability of DNDC to accurately simulate the observed N_2O emissions from the Dalby site confirms the models potential as a potentially feasible means of simulating the emissions for the entire season. Simulated daily N_2O and N_2 losses for the full season at Dalby in 2005/06 are presented in Figure 3. Note the increase in all emissions during mid season when the soils were moist for long periods of time and soil temperate was also elevated.

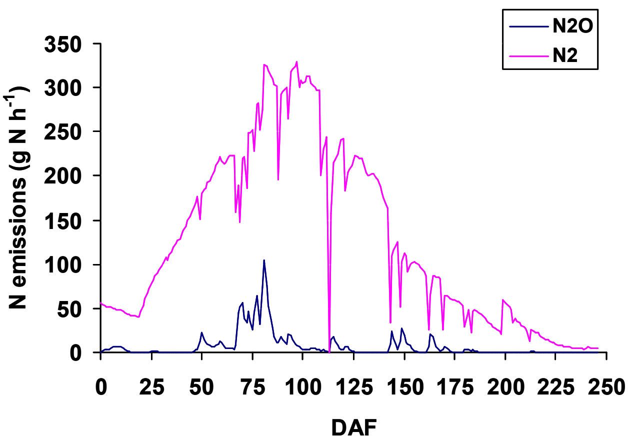

Figure 3. Simulated N_2O and N_2 emissions from a black clay at Dalby, Queensland (2005/06) fertilised with a split application of 207 kg N (DAF – Days after Fertiliser applied).

Total simulated emissions of N_2O and N_2 for the 2005/06 season were 1.7 and 30.7 kg N/ha, respectively. The 1.7 kg N/ha for N_2O is equivalent to 0.83% of the fertiliser applied during the season, and significantly below the default value of 1% suggested by the IPCC for N applications. The fact that the 207 kg N/ha was a split application over many months has played a large part in the low % emission of N_2O. The total N emission (N_2 + N_2O) is equivalent to 16% of the N application for the season, and the N_2/N_2O ratio is 18/1.

Conclusion

Typical on-farm N_2O emissions from irrigated black clays where split applications of N are applied to cotton are 0.83% of applied N, with total gaseous N losses (excluding NH_3) being estimated (through simulation) as 16% of the applied N. The practice of split applications is increasing across the cotton industry and its positive impact on reducing emissions is obvious, however more work on the N_2 component of N loss is required before a final total N loss figure can be confirmed. Substantial leakage of nitrate from beds to furrows has been experimentally confirmed in the on-farm component of this project and is a significant source of N loss and N_2O emissions. This is an area of concern, considering the majority of growers currently use furrow irrigation.

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