Maintaining yield / reducing nitrogen losses in water: a sustainable solution for sugarcane production systems

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Abstract
Nitrogen (N) is critical for crop production, but N losses to water from farming systems have the potential to negatively impact ecosystem health. Along the north-eastern Australian coast, N pollution of groundwater and environmental damage to the Great Barrier Reef have been attributed to N fertiliser applications. Sugarcane is the dominant intensive landuse in these catchments, and consequently the sugarcane industry's N management practices are coming under increasing scrutiny. A three year experiment was conducted in sugarcane on the Wet Tropical coast of north-east Australia to measure crop production and dissolved inorganic-N (DIN) losses from two different N fertiliser management practices: The farmers' conventional application rate (average 180 kg N/ha/yr) and a reduced rate based on replacing N exported in the previous crop (average 95 kg N/ha/yr). Losses of DIN to groundwater were measured in one of those years. The reduced N rate maintained yield over all three years and did not lead to any soil mineral N depletion in comparison with the conventional fertiliser rate. As well, DIN losses in surface water were 72%, 48% and 66% lower in the three years compared to the conventional practice, and losses to groundwater were 58% lower in the first year. While the proportion of DIN lost from sugarcane that reaches the Great Barrier Reef lagoon remains uncertain, these results suggest that adoption of N rates based on replacing N exported in the previous crop can sustain yield (without 'mining' the soil) and help reduce the impacts of DIN.

Key Words
Runoff; Deep drainage; Nitrogen replacement; Water quality; Nitrogen use efficiency

Introduction
Nitrogen (N) is critical for crop production, but N losses to water from farming systems have the potential to negatively impact ecosystem health. Pollution of aquatic and marine ecosystems from N fertiliser is an issue facing many agricultural regions around the world (Howarth, 2008), and how to minimise pollution while maintaining agronomic productivity is a challenge. In north-eastern Australia, elevated concentrations of dissolved inorganic N (DIN) have been detected in rivers draining to the World Heritage listed Great Barrier Reef (GBR; Bramley and Roth, 2002; Mitchell et al., 2009). It is estimated 80% of the total anthropogenic load of DIN to the GBR is sourced from fertiliser (Waterhouse et al., 2012).

Sugarcane (*Saccharum officinarum* L.) is by far the dominant crop in catchments draining to the northern GBR (Mackay north to Mossman). The majority of sugarcane is grown on coastal lowlands, floodplains and deltas, close to estuaries, creeks and river mouths (Furnas, 2003). This proximity to the end of catchments means that, during the large annual wet-season rainfall events, water has a very short residence time before reaching the GBR lagoon. It is during these large rainfall events when most of the N export occurs (Mitchell et al., 1997). Additionally, N lost via deep drainage has the potential to move via sub-surface flow to surface water (Rasiah et al., 2010).

In Australia, sugarcane receives annual N fertiliser applications in excess of 150 kg N/ha (Thorburn and Wilkinson, 2012). However, not all applied N is exported in the crop (Thorburn et al., 2011). N may be lost from the sugarcane system in gaseous forms via volatilisation or denitrification, or in water via surface runoff or deep drainage. N may also be recycled in crop residue, or immobilised in soil organic matter. There are sparse data on N losses in surface runoff and deep drainage water from sugarcane production (Bartley et al., 2012). For these reasons, this paper investigated whether reducing the rate of N fertiliser application is an appropriate management practice to lower losses of DIN in surface water runoff and deep drainage, and importantly, if lower N fertiliser application can maintain yield.

Methods

Data were obtained from a field site in the Mossman sugarcane growing district of north Queensland, Australia (approximately 16°24'S, 145°24'E). The average annual rainfall at the site is 2750 mm and soil at the experimental site was a well drained brown Dermosol (Isbell, 1996) formed on alluvium. Soil organic carbon was 1.2% in the top 0.2 m. The three year experimental programme was initiated after harvest of a second ratoon sugarcane crop in 2003, with each growing season referred to as the year in which the crop was harvested i.e. 2004, 2005 and 2006.

The experiment consisted of two N fertiliser management strategies randomly assigned to three plots each. Plots were 13 rows wide (at 1.57 m row width), a row length of approximately 175 m, and a single guard row between each plot. The two N fertiliser management strategies were a constant N application rate each year equal to the normal N rate the farmer applied to all his crops (N_{farm}; 180 kg N/ha), and an application rate based on N replacement (N_{repl}; Thorburn et al., 2011; 95 kg N/ha). For the N_{repl} treatment, applications (kg/ha) were determined by multiplying the previous fresh weight yield (in tonnes/ha) by the constant 1.0 to determine the fertiliser application rate (in kg N/ha; Thorburn et al., 2011). All fertiliser was applied in the form of urea in a single dose between 36 and 54 days after harvest.

One plot from each treatment was instrumented to measure and sample surface runoff water with a ‘9 inch’ Parshall flume to direct runoff from 11 rows plus ten inter rows to the flume. To measure deep drainage volume, and allow collection of leachate, five barrel lysimeters were installed in each instrumented plot prior to fertilising in 2003. All samples were collected from the field within 24 hours of the event. Lysimeters were only monitored in the first year.

Water samples from both runoff and deep drainage were stored frozen prior to laboratory analysis. Runoff samples were analysed for total N, and dissolved inorganic nitrogen (DIN) via a colorimetric procedure (Rayment and Higginson, 1992). Runoff load was calculated from the flow weighted total N or DIN for each event using runoff data and samples analysed during the rising, peak and falling stages of runoff flow for that event. Deep drainage samples were analysed for total N and nitrogen oxides (NO_x) via a colorimetric procedure (Rayment and Higginson, 1992). Loads of NO_x and total N lost via deep drainage were calculated by averaging the concentration from the five lysimeters in each treatment and multiplying by the calculated average deep drainage volume.

In each plot at harvest, fresh weight, dry weight and N content was measured on above ground biomass, and the portion of the crop exported, to determine N taken up, exported, and recycled to the soil surface. Treatments were compared via a one-way analysis of variance test (using Statistix™ v9).

Soil mineral N was determined from all plots at the commencement of the experiment, and after each harvest. Soil mineral N (to 1.8 m) was plotted for all years of the experiment for each treatment, and a regression line fitted. Linear regressions were used to represent the change in soil mineral N over the life of the experiment, and the slope of these regressions compared between treatments using a one-way analysis of variance test (using Statistix™ v9).

Results

In each of the three monitoring periods, total losses of DIN in surface water runoff were lower in the N_{repl} treatment than the N_{farm} treatment (Figure 1). DIN was 72%, 48% and 66% lower in the N_{repl} treatment in the 2004, 2005 and 2006 monitoring periods respectively (Figure 1). Losses of total N in surface runoff, measured in 2004 only, were 34% lower in the N_{repl} treatment (Figure 1).

During 2004, losses of total N via deep drainage were much greater in the N_{farm} treatment (26.11 kg/ha) than the N_{repl} treatment (10.99 kg/ha; Figure 1). Over the 2004 monitored period, NO_x as a proportion of total N lost via deep drainage represents 93% in the N_{farm} treatment (24.4 kg/ha) and 82% of total N lost in the N_{repl} treatment (8.99 kg/ha). In individual events, the proportion of total N lost as NO_x ranged between 68% and 100%, generally increasing as the monitoring period progressed.

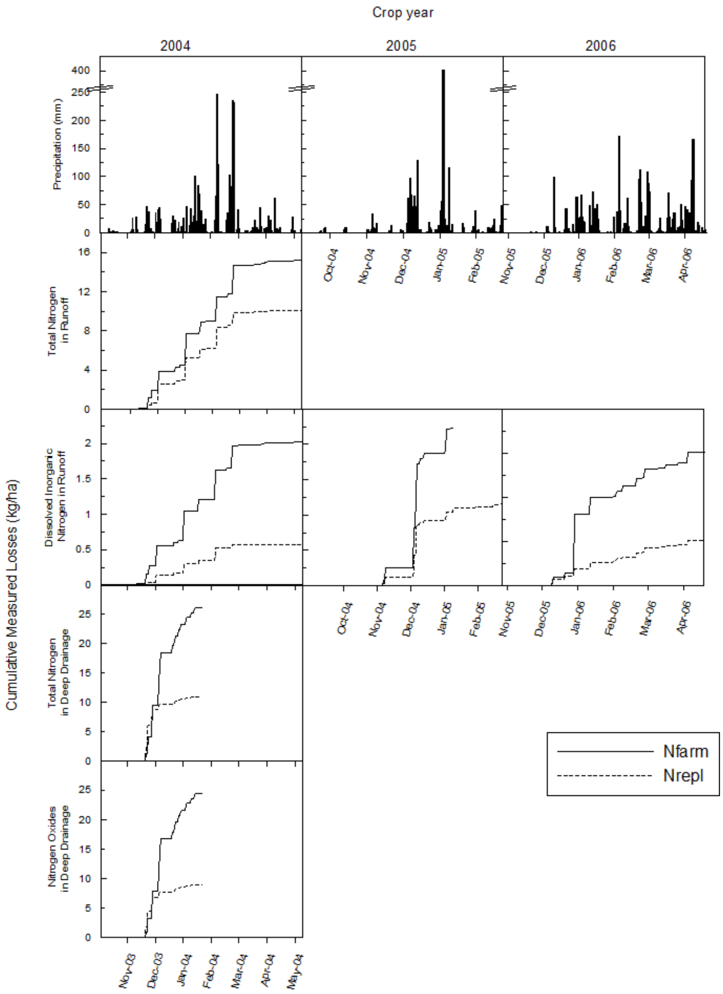

Figure 1. Rainfall and cumulative N losses in runoff water and deep drainage for crop year from normal farmers N application rate (N_{farm}) and lower fertiliser rate based on replacing N exported in previous crop (N_{repl}).

Sugarcane yield did not differ significantly between the N_{farm} and N_{repl} treatments in any of the crops (Table 1). The total amount of N exported annually in harvested material ranged between 35 and 50 kg N/ha, and represented, on average, 0.63 and 0.64 kg N/tonne of harvested cane for the N_{farm} and N_{repl} treatments, respectively (Table 1). N recycled as crop residue (trash) represented approximately 35% of the above ground biomass N in 2004 and 2005 (Table 1).

Table 1. Agronomic measurement means for all crops. For each measurement and year there were no significant differences at *P*<0.05.

Crop	Yield (t/ha)		N exported in crop (kg/ha)		kg N/tonne harvested		Trash N (kg/ha)	
	N_{farm}	N_{repl}	N_{farm}	N_{repl}	N_{farm}	N_{repl}	N_{farm}	N_{repl}
2004	76	71	50	45	0.66	0.63	30	26
2005	77	75	43	46	0.56	0.61	20	27
2006	55	51	37	35	0.67	0.69	36	31

There were substantial amounts of soil mineral N in the profile to 1.8 m (almost 100 kg N/ha at the initiation of the study) and large year to year variation. However, regressions of the temporal trends in soil mineral N (to 1.8 m) in the N_{farm} and N_{repl} treatments over the term of the study do not differ significantly (P>0.05), indicating no treatment effect on soil mineral N.

Discussion

The results of this study indicate lower N fertiliser application to sugarcane production systems in wet tropical environments could lower DIN losses in surface runoff water, as was observed in each of the three years of this study (Figure 1). The results additionally show, in a single year, losses of nitrogen oxides via deep drainage are lower in the reduced fertiliser application rate treatment. Importantly, productivity was not affected by the lowered N application rate. This result could not be attributed to short term 'mining' of soil mineral N, as the soil mineral N stores did not decrease in the N_{repl} treatment. This result is consistent with other testing of the N replacement practise over four years at five sites across the Australian sugarcane industry (Thorburn et al 2011).

The N loss findings presented here are limited in that they are from a small trial, and could not be seen to represent the entire sugarcane industry, however, the observation that reducing N applications leads to reduced N losses in surface runoff water and deep drainage without negatively impacting yield are promising. Given the ecological importance of DIN (De'ath and Fabricius, 2010; Brodie et al., 2011), and its sourcing from fertiliser use, the potential implications are important: current DIN losses from sugarcane production systems could be reduced by the adoption of management practices that reduce N application, while maintaining yield.

Conclusion

By lowering N fertiliser application from conventional rates to a rate based on replacing the N exported in the previous crop, N losses were reduced in surface runoff water and deep drainage. The lower N application rate did not lower yield, or 'mine' the soil, to achieve this yield maintenance. Given the ecological significance of DIN contributions to the GBR, identifying management practices that reduce DIN losses from sugarcane production systems in GBR catchments is important. The N replacement technique provides one such technique to achieve lower DIN losses while maintaining sugarcane productivity. Given the limited nature of the experimental design reported here, this preliminary experiment should be tested under a diverse range of conditions to verify these results.

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