Nitrogen fertiliser management of sugarcane crops for meeting global environmental challenges

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Introduction

Controlling N losses from cropping systems is important because of the impacts of N on human health and ecosystems (predominantly as NO_3) and its role in contributing to climate change (through N_2O emissions). These are challenging issues for sugarcane production, which has generally high use of N fertiliser (Roy *et al.*, 2006) and is increasingly used for biofuel production (Macedo *et al.*, 2008). It is unlikely that traditional N fertiliser recommendations for sugarcane will meet these challenges. In Australia for example, recommendations have moved from widely applied fixed rates (often 160 kg/ha/crop; Calcino 1994) to include consideration of potential crop yields and soil N mineralising potential (e.g. Schroeder *et al.*, 2006) in an effort to reduce N use. However, these newer recommendations will still result in over-application of N where *actual* production is less than potential, as common occurs.

Sugarcane is a deep rooting, semi-perennial crop (i.e. it is allowed to ratoon a number of times after annual harvesting) grown in subtropical and tropical areas where soil N cycling is often rapid. This rapid N cycling allows large amounts of N to be immobilised and subsequently mineralised over the long term (Meier *et al.*, 2006) where it can be efficiently retrieved by the deep root system (Thorburn *et al.*, 2003). Therefore sugarcane may be well suited to a more ecologically-based approach to N management (Drinkwater and Snapp, 2007), where N fertiliser applications are geared to maintaining soil N stores so they can provide the crop's N needs, rather than more directly 'feeding' the crop.

Such an ecologically based N management system, known as N Replacement, was proposed for sugarcane by Thorburn *et al.* (2004). They linked N applications to crop N off-take in the previous crop. The assumption was that, if the yield of the coming crop was larger than that of the previous crop, additional N requirements would be supplied from soil N stores. Conversely, these N stores would be 'topped up' when a small crop followed a large one. They suggested a potential saving in N fertiliser of up to 40% compared with common N fertiliser applications in Australia, and consequently the N surplus (an estimate of the N potentially lost to the environment; Meisinger and Randall, 1991) may be reduced by 90%. In this paper we report on 11 field experiments established to test this concept over two to four crops in the diverse soils and climates of the Australian sugarcane industry.

Methods

Experiments were established on commercial farms in 2003 or 2004 located from the wet tropics around Cairns (~16°S - Mossman, Mulgrave and Innisfail, Table 1), to the dry tropics near Townsville (~19°S - Burdekin), and the sub-tropics (~25°S to 28°S - Bundaberg, Maryborough and Condong). Crops at sites BK-1, BK-2, BU-1 and MB-1 were irrigated and the others rainfed. The irrigated crops, except at BU-1, were burnt at harvest. Others were harvested unburnt with all residues retained on the soil surface. The N Replacement (NR) system was compared with the farmers' conventional N fertiliser management (NF). The amount of N fertiliser (kg/ha) applied in the NR approach was targeted to be 1 kg N/t cane harvested in the previous crop where residues were retained and 1.3 kg N/t cane where the crop was burnt (Thorburn *et al.*, 2004). This is less than current recommendations in Australia (Schroeder *et al.*, 2006) or more generally (Roy *et al.*, 2006). In five of the experiments a lower N rate treatment (NL) was also included to examine the time taken for productivity to decline as a consequence of low N applications. The lower rate was approximately equivalent to that which would occur with the NR scheme following a very poor crop.

Table 1. Details of the experimental sites and the average annual N applied in different treatments (NL-N Low; NR-N Replacement; NF-N Farm).

Site code	Region	Soil texture (0-0.6 m)	Soil C (%) (0-0.3 m)	Reps	Average N applied (kg/ha)		
					NL	NR	NF
BK-1	Burdekin	sandy clay loam	0.77	2		159 [a]	318 [a]
BK-2	Burdekin	sandy clay loam	0.84	2		217 [a]	326 [a]
BU-1	Bundaberg	sandy loam to sandy light clay	0.75	3	35	95	140
CD-1	Condong	light clay	2.03	2	67	143	146
IN-1	Innisfail	sandy clay	1.87	3	68	88	168
IN-3	Innisfail	light clay	2.16	1		117	144
MB-1	Maryborough	light clay	1.21	1	63	128	160
MB-2	Maryborough	sandy clay loam	1.12	3	55	111	152
ML-1	Mulgrave	sandy clay	1.17	1		135	180
MS-1	Mossman	sandy clay	1.22	3		95	177
MS-4	Mossman	light clay	1.24	1		93	174

[a] N applications include N applied through nitrate contained in irrigation water.

Generally the sites had been managed using the farmers' normal practice prior to the experiments. The exception was BU-1, where the experiment was established in the first ratoon crop of a pre-existing N rate experiment (Thorburn *et al.*, 2003). In this experiment the NR treatment was applied to plots that had received **no** N fertiliser in the preceding plant crop (yielding 83 t/ha). Also, unlike the other sites, the NL treatment had received a low rate of fertiliser since 1996.

The experimental layout at each farm was decided jointly with collaborating farmer groups. Seven experiments were established as randomised designs with treatments replicated, while four were non-replicated demonstration experiments (Table 1). Plots were generally large enough to allow harvested cane yield and sugar content to be determined from commercial harvesting and milling operations. Crop biomass and N concentrations were determined prior to harvest to allow calculation of crop N dynamics. Where treatments were replicated and run over multiple harvests, the results were subject to analysis of variance using a strip-plot design.

The surplus of N was calculated for each treatment as the difference between N applied and that lost through crop harvest and, where applicable, trash burning. The amount of N in the crop and trash was determined from mass and N concentration in the harvested cane and trash. N surpluses are calculated from the sum of all the harvest years and reported as an annual average.

Results

Yields were generally similar in the NR and NF treatments (Figure 1), and generally below the yield potential for these areas (Schroeder *et al.*, 2006). There were no significant yield differences in the replicated experiments, despite the fact that N applications were on average 64 kg/ha/crop lower using the NR treatment than the NF. Yields in the NL treatment were 10-30 t/ha lower than those in the treatments receiving higher N (Figure 1), especially in the 2nd and 3rd crops after the treatments were imposed.

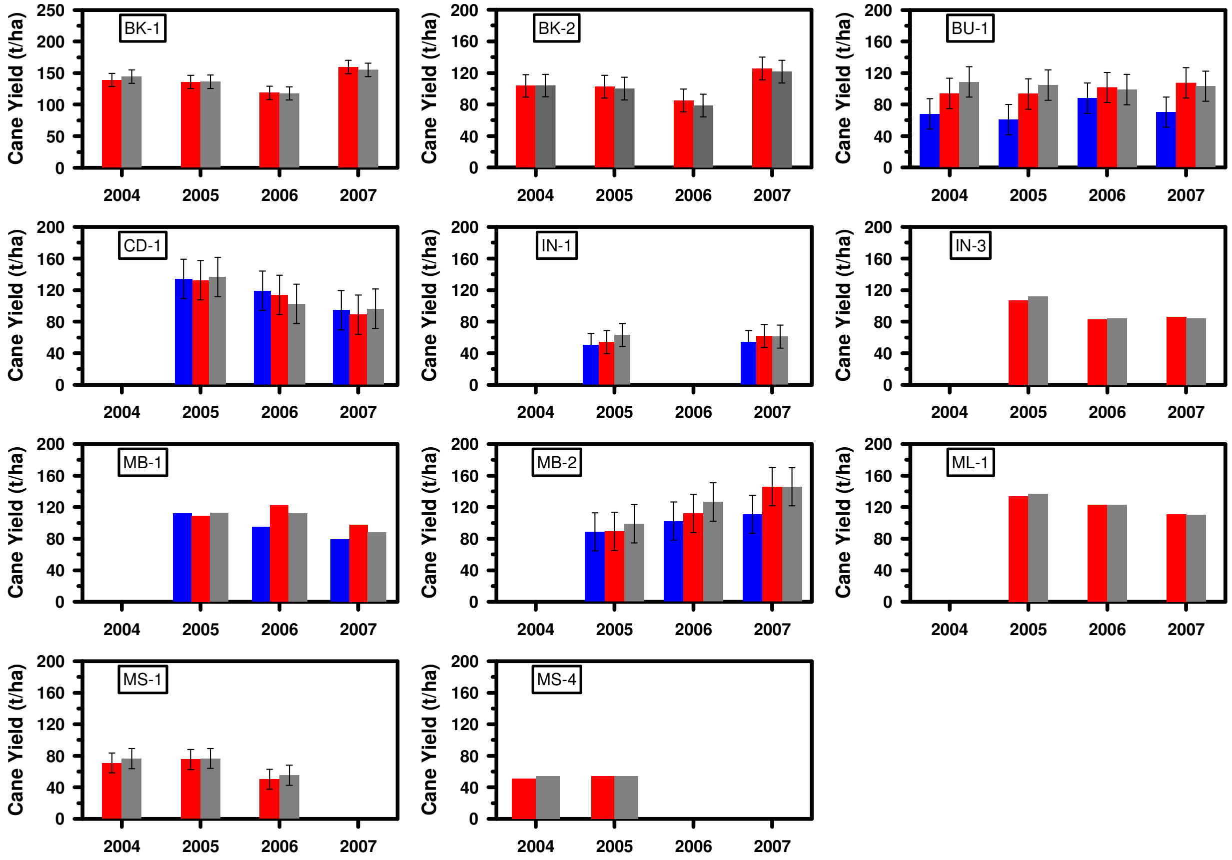

Fig. 1. Cane yields of sugarcane crops harvested from experiments comparing the N Replacement system (red bars) with farmers' conventional N fertiliser management practice (grey bars) and, at some sites, a lower rate of applied N (blue bars). In replicated experiments errors bars indicate the critical difference for comparing between treatments. Note: The BU-1 experiment was established on a site where soil N had been previously rundown; and there are no results for site IN-1 in 2006 due to cyclone damage.

There was a trend for yields in the NR treatment to be lower than those in the NF treatment in the first crop after the treatments were imposed, with little or no difference in later crops. This trend was most marked at the BU-1 site. At this site the NR treatment was established on a plot in which soil N reserves had been run-down. So the relationship between yields and N applications in the 1st two crops was not surprising. More surprising was the higher average yields in the NR treatment for the 3rd and 4th crops at this site. This result, together with the similar general behaviour observed at the other sites suggested that the crops were 'compensating' for the lower N application. This 'compensation' could be due to biological N fixation. However, N fixation is generally not significant in Australian sugarcane crops (Biggs *et al.*, 2002) and has been discounted as an N source to crops at the BU-1 site (Thorburn *et al.*, 2003). Alternatively, the crops may be responding to the lower N application through deeper root development and increased N uptake efficiency (Smith *et al.*, 2005).

Cane N concentrations, a major component of crop off-take of N, were variable between sites (Figure 2), e.g. ranging from ~0.3 % in some crops at sites BK-1 and BK-2 to <0.1% at MB-2. Cane N concentrations also varied between years, e.g. 0.2 % in 2005 and 0.1% in 2006 at site IN-3. They also tended to be lower in the NL treatment, presumably responding to the markedly lower N applications in this treatment (Table 1). There was little difference in N concentrations in cane from the NR and NF treatments in most experiments, exceptions being sites BK-1 and ML-1 where there was a trend for cane N concentrations to be 0.02-0.05 % lower in the NR treatment. In the NR and NF treatments cane N concentrations were generally lower than those measured in Australian sugarcane crops during the early 1990's (Wood *et al.*, 1996). The unexpectedly low cane N concentrations may possibly be due to physiology of modern varieties.

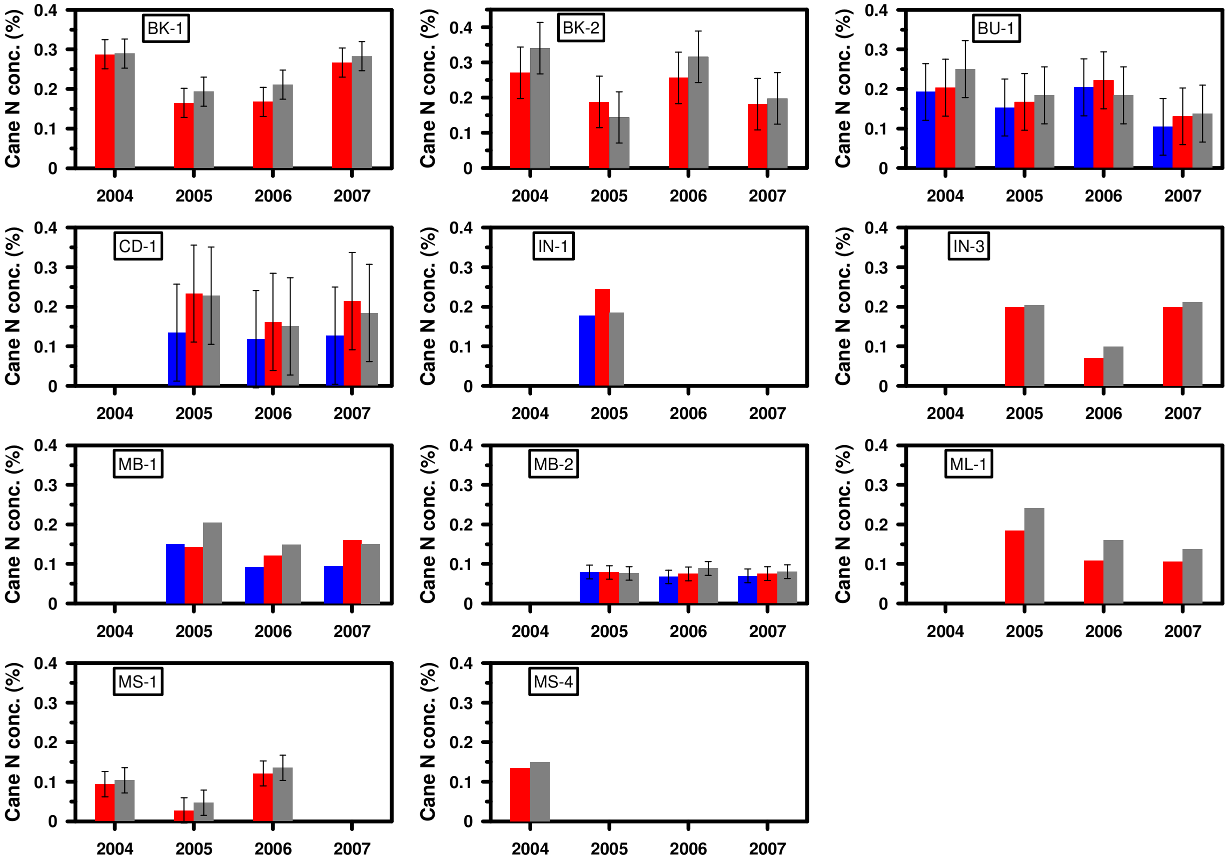

Fig. 2. Concentrations of N in cane of sugarcane crops in the experiments. Treatment designations are the same as in Figure 1. Note: Samples at sites IN-1 and MS-4 were not obtained in all crops.

The amount of surplus N generally increased with increasing N applications, being -28 to 29 kg/ha/crop in the NL treatment, 26 to 156 kg/ha/crop in the NR treatment and 13 to 220 kg/ha/crop in the NF treatment (Figure 3). The average surpluses were ~40 % lower in the NR treatment compared with the NF treatment, excluding site CD-1. This reduction is less than that foreshadowed by Thorburn *et al.* (2004), the reason being that the N concentrations measured in most crops (Figure 2) were lower than the 0.3% assumed by Thorburn *et al.* (2004) based on previous measurements (Wood *et al.*, 1996).

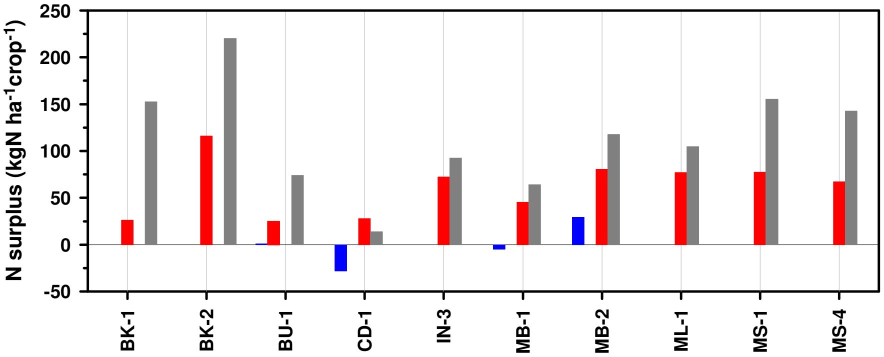

Fig. 3. The N surplus (i.e. the difference between N applied and that lost in harvested cane and, at some sites, burnt residues) averaged over all sugarcane crops harvested from the experiments. Treatment designations are the same as in Figure 1. Note: There are no results for site IN-1 in 2006 due to cyclone damage.

Discussion

These results suggest the N replacement concept has promise for meeting the productivity needs of N fertiliser management in sugarcane, while reducing potential environmental losses of N. Yields were similar to those with higher and more conventional (Schroeder *et al.*, 2006; Roy *et al.*, 2006) applications of N (Figure 1), especially in the 2nd and subsequent crops after the treatments were imposed. N surpluses (Figure 3), and so potential environmental impacts (Meisinger and Randall, 1991), were also reduced by ~40% compared with conventional N management. These results, while encouraging, were obtained over relatively short times (2-4 years, Figure 1). Further field testing will show whether the NR concept is sustainable in the long term. Previous simulations of the concept suggest they will be (Thorburn *et al.*, 2004).

The improved outcome of the NR system over the farmers' conventional management was potentially due to a number of factors. Firstly, yields in all treatments were generally lower than potential yield benchmarks in the regions which drive current recommendations on N management. Secondly, the lower than expected cane N concentrations (Figure 2) at most sites mean that the crops' N needs were lower than anticipated. Thirdly, it suggests that the philosophy of drawing on N reserves in the soil to buffer some of the short term differences between crop N needs and N supply from fertiliser is applicable in sugarcane production. This final point suggests that the concept of applying N to 'feed' potential yields may not be necessary for sustainable sugarcane production, particularly when farmers' yields do not realise their potential. A more ecologically-based approach to N management, where fertiliser applications are geared towards maintaining soil N stores, as advocated by Drinkwater and Snapp (2007), may be applicable to sugarcane.

The results from these experiments allow us to explore the degree to which N fertiliser applications need to match 'expected yields', and hence the degree of buffering soil N reserves provided to these sugarcane crops. Since in the NR system N applied is based on yield of the **previous** crop, N applications will only be equal to the 'needs' of the coming crop if yields are constant over a number of crops. Where yields increase through time, N applications will be lower than those needs, as would be the case when yields are higher than expected. This situation happened in the NR treatment at site MB-2. Yields of the 2006 and 2007 crops were 25 and 30% higher than the previous crop (Figure 1), resulting in **actual** N applications of ~0.8 kg N/t cane relative to the achieved yield. Yet, applying extra N fertiliser (average of 47 kg/ha/crop) in the NF treatment in these years did not significantly increase yield, particularly in the 2007 crop. Additionally, the NR treatment at the BU-1 site was established following a crop that received **no** N, yet after two crops yields had recovered to averages greater than those of the NF treatment that had received 45 kg/ha/crop extra N fertiliser. These results show that, from crop to crop, actual yields can be considerably higher than expected yields without N supply being limiting. As hypothesised by Thorburn *et al.* (2004) in conceiving the NR concept, the soil N cycling processes provided sufficient N for crop N needs in the N replacement system in the short term, and it is more important to match N applications to longer-term actual production.

The unexpectedly low cane N concentrations (Figure 2) suggest that there may be potential for further reductions in N fertiliser applications to these sugarcane crops. Rather than seeking N rates for optimum yield, a more useful approach for determining the N needs of sugarcane crops may be to ask the question; what is the minimum long-term N surplus required to maintain crop yields? The NR treatment in one-year crops had an average N surplus of 60-70 kg/ha (Figure 3), or ~0.5 kg N/ t cane, and this was sufficient to maintain productivity (Figure 1) compared with the higher N applications of the NF treatment (Table 1). It was also sufficient to overcome a deliberate rundown of soil N reserves at the BU-1 site within one or two crops. The question now is whether productivity can be maintained at lower N surpluses in these environments? If it can, there are further gains to be made in lowering N fertiliser applications and hence the environmental impacts of sugarcane production.

Acknowledgements

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