

## EVALUATING AN ECOLOGICALLY-BASED SYSTEM FOR SUSTAINABLE MANAGEMENT OF NITROGEN FERTILISER

By

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### Abstract

SUSTAINABLY managing N fertiliser is an increasing challenge for sugarcane production, as losses of N impact the health of ecosystems and contribute to climate change (through emissions of the greenhouse gas nitrous oxide). The N Replacement (NR) system is a new, ecologically-based concept for N management in sugarcane designed to meet this challenge. The NR system aligns N applications with actual cane production, rather than potential production, by relying on soil N reserves to buffer differences in crop N needs and N fertiliser supply in individual crops. We evaluated the NR system in 11 on-farm experiments in Australia, conducted over a wide range of environments for up to five years. Average yields in the NR treatment were similar to those achieved with the farmers' conventional N management that had average N applications 66 kg/ha greater than in the NR treatments. Yields increased relative to the farmers' conventional N management through time, from ~5 t/ha lower in the first crops of the experiments to 2.6 (standard error = 1.2) t/ha higher in the fourth, suggesting a physiological response in the crops to the variable N applications in the NR system. The crop N surplus, an estimate of N potentially lost to the environment, was 55% lower in the NR treatment compared with conventional N management. This reduction in N surplus was not as great as had been anticipated, as N concentrations and N uptake in cane for most crops in all treatments were lower than those previously reported. The results show that the ecologically-based N Replacement system may deliver superior environmental outcomes without significantly reducing production. The results also show that predicting yield of the coming crop, a common basis for N management, is not necessary in sugarcane N management, provided N applications and production are matched in the longer term.

### Introduction

Controlling N losses from cropping systems is important because of the impacts of N on human health and ecosystems (predominantly as NO<sub>3</sub>) and its role in contributing to climate change (through N<sub>2</sub>O 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. Potential crop yields are a feature of many recommendation systems (e.g. Legendre, 2001; Schroeder *et al.*, 2006) and so result in over-application of N in the common situation where actual production is less than potential (Meyer *et al.*, 2007).

Sugarcane is a deep rooting semi-perennial crop (i.e. it is allowed to ratoon after 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 (Ng Kee Kwong *et al.*, 1986; Meier *et al.*, 2006) where it can be efficiently retrieved by the deep root system (Smith *et al.*, 2005). 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 (NR), 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 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) may be reduced by 90%.

In this paper we report on 11 field experiments established to test this concept in the diverse soils and climates of the Australian sugarcane industry. As well as evaluating whether the NR system can maintain sugarcane productivity with lower N fertiliser inputs and environmental impacts, we also discuss the implications of the results for general sugarcane N management strategies.

## 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 trash retained on the soil surface. The 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 trash was retained and 1.3 kg N/t cane where the crop was burnt (Thorburn *et al.*, 2004). This is less than general application rates to sugarcane (Roy *et al.*, 2006) and, particularly where trash is retained, less than current recommendations in Australia (Schroeder *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	Texture (0–0.6 m)	Total C (%) <sup>a</sup> (0–0.3 m)	Reps	Average N applied (kg/ha)		
					NL	NR	NF
BK-1	Burdekin	Sandy clay loam	0.77	2	nab	159	318
BK-2	Burdekin	Sandy clay loam	0.84	2	na	218	326
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	149
IN-1	Innisfail	Sandy clay	1.87	3	68	88	168
IN-3	Innisfail	Light clay	2.16	1	na	110	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	na	129	181
MS-1	Mossman	Sandy clay	1.22	3	na	95	177
MS-4	Mossman	Light clay	1.24	1	na	93	174

<sup>a</sup> Soil C concentration determined by combustion with a LECO CNS analyser.

<sup>b</sup> The NL treatment was not established at every site.

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 lower-than-recommended rate of fertiliser since 1996.

A participatory approach was taken to the experimental designs at each farm, so these were 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).

All cultural practices and the timing of these operations were determined by the collaborating farmers. This approach was taken to ensure crop production reflected that achieved on commercial farms, and not higher yields often achieved in more carefully managed experiments.

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). However, there was a trend for yields in the NR treatments to be less than those in the NF treatment in the first year of the experiment, but increase relatively in each successive year.

In the five experiments in which at least four crops were grown, the yields in the NR treatment were 2.0 (standard error = 0.6) and 2.6 (1.2) t/ha greater than those in the NF treatment in the 3rd and 4th crops, respectively.

The relative increase in yield in the NR treatment 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 yield-response to increasing N applications in the first two crops was not surprising.

More surprising was the higher average yields in the NR treatment for the third and fourth crops at this site.

There were no significant yield differences in the replicated experiments, despite the fact that N applications were on average 66 kg/ha lower using the NR treatment than the NF.

Yields in the NL treatment averaged 11 t/ha lower than those in the NF treatment receiving higher N (Figure 1).

The biggest difference was at the BU-1 site where the NL treatment had been imposed for 8 years prior to this experiment, and so soil N is likely to have run down.

Excluding this site, the average yield reduction was 6.2 t/ha, trending from 5 t/ha in the first crop after the treatments were imposed, to 8 t/ha in the third.

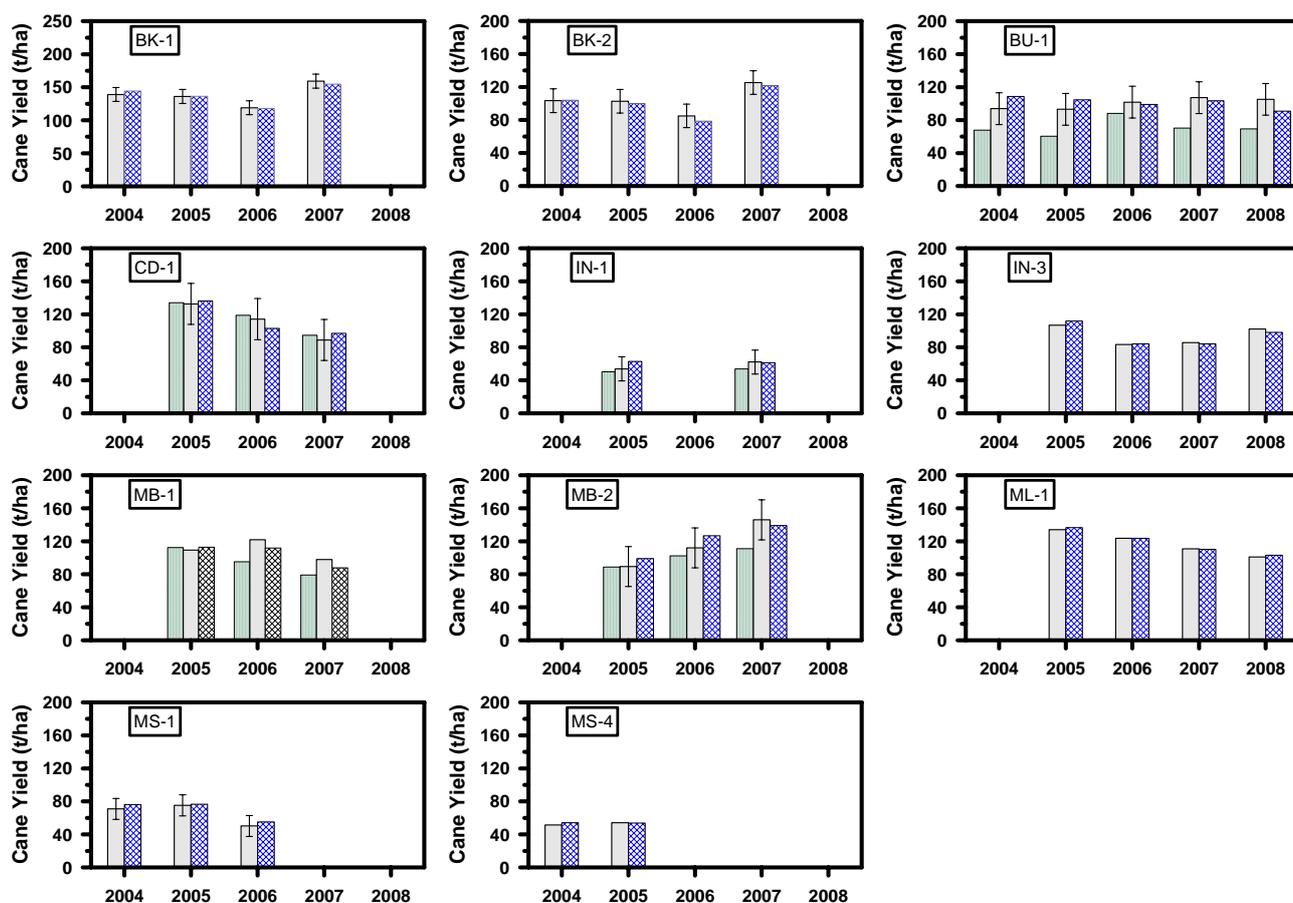


Fig. 1—Cane yields of sugarcane crops harvested from experiments comparing the N Replacement system (grey bars) with farmers' conventional N fertiliser management practice (blue hatched bars) and, at some sites, a lower rate of applied N (green stippled bars). In replicated experiments, error bars indicate the critical difference ( $p = 0.05$ ) 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.

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 in three of the four years for cane N concentrations to be lower in the NR treatment.

The amount of surplus N generally increased with increasing N applications, averaging 5 kg/ha in the NL treatment, 63 kg/ha in the NR treatment and 141 kg/ha in the NF treatment, although the values were highly variable across sites (Figure 3).

Despite the variability, N surplus in the NR treatment was less than those in the NF treatments at all sites, except CD-1 where there was little difference between the N fertiliser applied in these two treatments. The average reduction in N surplus (55%) was less than that predicted 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).

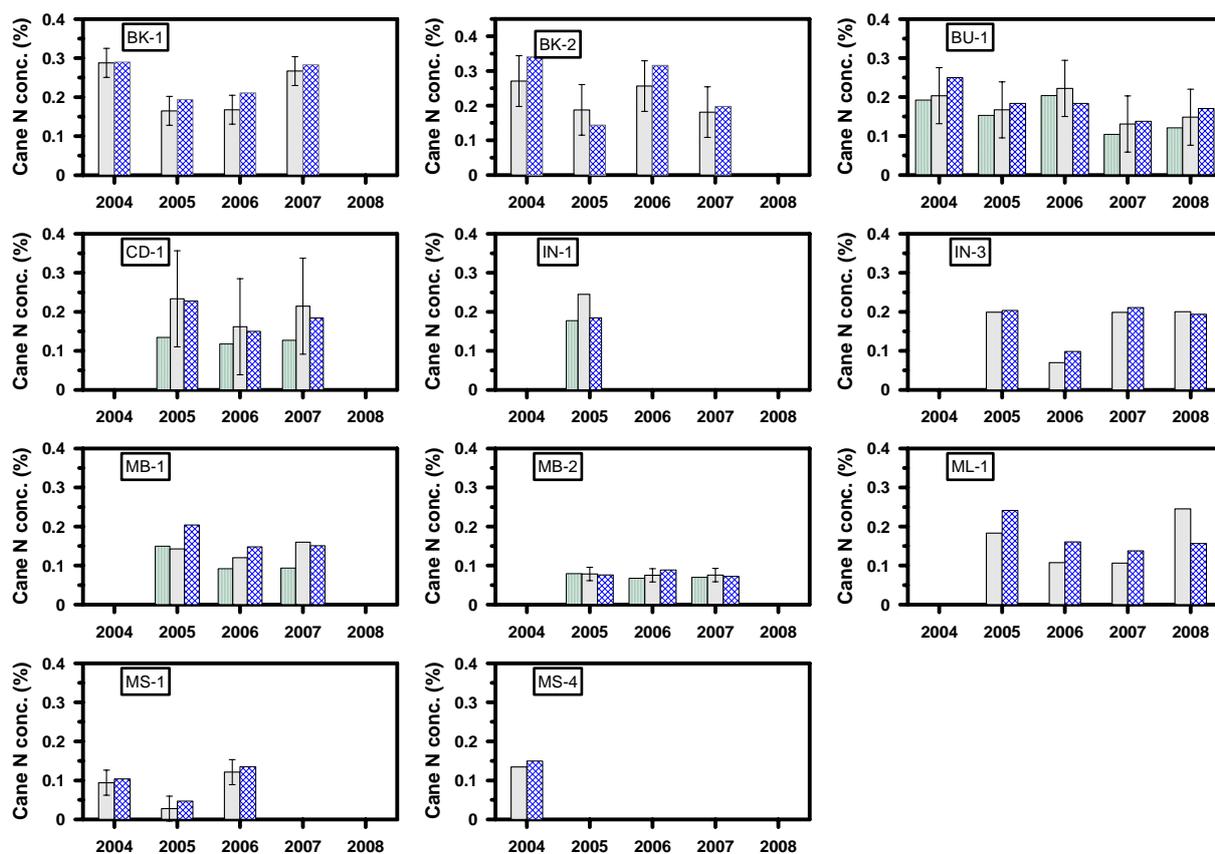


Fig. 2—Concentrations of N in cane of sugarcane crops in the experiments. Treatment designations are the same as in Figure 1. Note: Samples at sites IN-1 and MS-4 were not obtained in all crops.

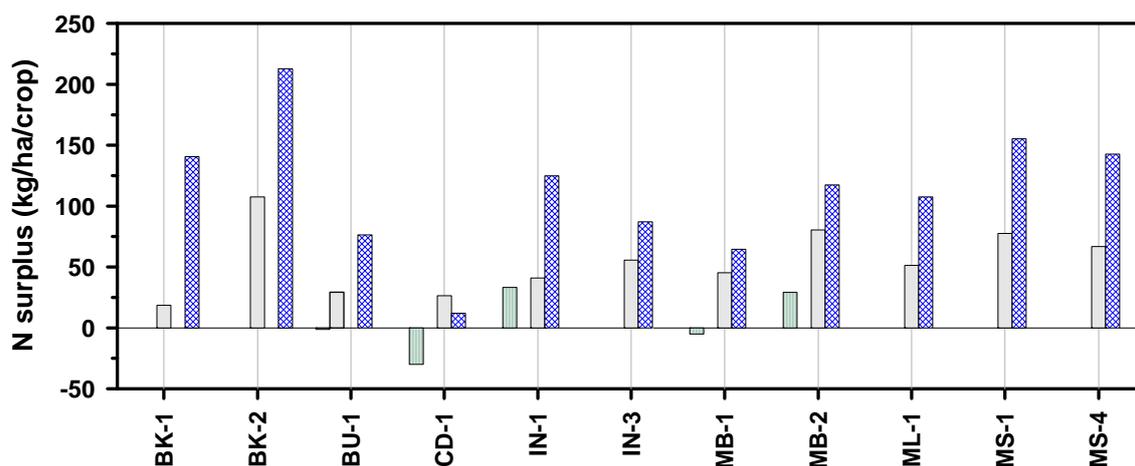


Fig. 3—The N surplus (i.e. the difference between N applied and that lost in harvested cane and, at some sites, burnt trash) averaged over all sugarcane crops harvested from the experiments. Treatment designations are the same as in Figure 1. Note: There are no results for site IN-1 in 2006 due to cyclone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

### Discussion

These results suggest the NR system has promise for meeting the productivity needs of N fertiliser management in sugarcane while reducing potential environmental losses of N for the range of conditions represented in the 11 experiments of this study. 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 second and subsequent crops after the treatments were imposed. N surpluses (Figure 3), and so potential environmental impacts, were also reduced by ~55% compared with conventional N management.

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 thinking on farmers' N management. For example, potential yields in the regions in which the experiments were located were generally 120 t/ha, and 180 t/ha in the Burdekin region (Schroeder *et al.*, 2006). These yields were only reached or exceeded in 7 of the 37 crops grown in the experiments. And in those crops, e.g., CD-1 in 2005 or MB-2 in 2007 (Figure 1), there was no evidence that the lower N applied in the NR treatment was limiting yields.

Secondly, cane N concentrations (Figure 2) were generally lower than expected from previous studies (Wood *et al.*, 1996) across all treatments and sites, meaning that the crops' N needs were lower than anticipated.

Thirdly, this improved outcome suggests that the philosophy of drawing on dynamic N cycling in sugarcane soils (Ng Kee Kwong *et al.*, 1986; Meier *et al.*, 2006) 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 actual 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, and so crops must draw on soil supplies, 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) 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 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.

There were some unexpected physiological responses in the crops of the experiment. Firstly, as discussed above, cane N concentrations (Figure 2) were generally lower than those previously measured in Australian sugarcane crops (Wood *et al.*, 1996). These unexpectedly low cane N concentrations may be possibly due to the physiology of modern Australian varieties which, if so, indicates that there may be potential for further reductions in N fertiliser applications to sugarcane crops. Rather than seeking N rates for optimum yield, a more useful approach for determining the

potential reductions may be to ask the question; what is the minimum long-term N surplus required to maintain crop yields?

The NR treatment had an average N surplus of 63 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 (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?

The second physiological response was the trend for yields in the NR treatments to increase relative to those in the NF treatment over successive crops (Figure 1). This result suggests that the crops were 'compensating' for the lower, but variable, N application in this treatment. Sugarcane crops can respond to N through deeper root development (Smith *et al.*, 2005), a possible explanation for the results in this experiment.

Such compensation, together with the lower than expected cane N concentrations observed in these crops suggest that there are further gains to be made in lowering N inputs to, and hence environmental impacts of, sugarcane production.

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## ÉVALUATION D'UN SYSTÈME ECOLOGIQUE DE GESTION DURABLE DE LA FERTILISATION AZOTEE

Por

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**MOTS-CLÉS: Excédent d'azote, Teneur en Azote de la Canne à Sucre, Rentabilité de l'exploitation, Meilleure Pratique de Gestion, Incidences sur l'Environnement.**

### Résumé

LA GESTION durable de la fertilisation azotée est un défi croissant de la production de canne à sucre, car les pertes en N affectent la santé des écosystèmes et contribuent au changement climatique (par des émissions de protoxyde d'azote, un gaz à effet de serre). Le système de remplacement de N (NR) est un concept nouveau concept, à base écologique, de gestion de N en canne à sucre, conçu pour relever ce défi. Le système de NR préconise des applications d'azote en accord avec la production réelle de canne, plutôt que la production potentielle, et tenant compte des réserves du sol en N pour tamponner les différences entre les besoins en N par la plante et les fournitures en azote par le sol. Nous avons évalué le système NR sur 11 essais menés sur exploitation en Australie, conduits sur un large éventail d'environnements pendant cinq années. Les rendements moyens dans le traitement NR furent similaires à ceux produits par la gestion conventionnelle de N des exploitants qui a nécessité des applications d'azote moyennes 66 kg/ha, bien plus grandes que celles des traitements NR. Comparés à la gestion conventionnelle, les rendements produits par le système NR a augmenté dans le temps, passant de ~5 t/ha dans les premières récoltes à + 2.6 t/ha dans le quatrième récolte, suggérant une réponse physiologique variable des plantes aux applications d'azote dans le système NR. L'excédent d'azote, potentiellement perdu vers l'environnement, était 55% plus faible dans le traitement NR qu'avec la gestion conventionnelle de N. Cette réduction d'excédent de N ne fut pas aussi grande que prévue, car les concentrations en N de la canne et la mobilisation de N par la plante dans la plupart des traitements furent inférieures à celles précédemment rapportées. Les résultats montrent que le système écologique de remplacement de N mobilisé peut améliorer l'impact environnemental sans réduire de manière significative la production. Les résultats montrent également que le rendement prévu, un critère commun du calcul de l'azote à fournir, n'est pas nécessaire dans la gestion de N chez la canne à sucre, si les applications de N et la production sont raisonnées à plus long terme.

## EVALUACIÓN DE UN SISTEMA BASADO ECOLOGICAMENTE EN EL MANEJO SUSTENTABLE DEL FERTILIZANTE NITROGENADO

Par

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Caña de Azúcar, Rentabilidad Finca (Campo),  
Mejor Práctica de Manejo, Impacto Ambiental.**

### Resumen

EL MANEJO sustentable de los fertilizantes nitrogenados es un desafío creciente para la producción de caña de azúcar, porque las pérdidas de N impactan la salud de los ecosistemas y contribuyen al cambio climático (a través de las emisiones de óxido nitroso como gas de efecto invernadero). El sistema de Reemplazo de N (NR) es un concepto nuevo, ecológicamente basado en el manejo del N en caña de azúcar diseñado para responder a este desafío. El sistema NR relaciona las aplicaciones de N con la producción actual de caña, más que con la producción potencial, teniendo en cuenta las reservas de N del suelo para atenuar las diferencias entre las necesidades de N del cultivo y la adición de fertilizante nitrogenado en cada cultivo. Evaluamos el sistema NR en 11 sitios experimentales en Australia, sobre un amplio rango de ambientes por un período de hasta cinco años. Los rendimientos promedios en los tratamientos NR fueron similares a aquellos registros de los agricultores con manejo convencional de N, que hicieron aplicaciones promedio de 66 kg/ha de N, más altas que en los tratamientos NR. Hubo incrementos de rendimientos relativos de los agricultores de manejo convencional de N a través del tiempo, desde menos de 5 t/ha en el primer cultivo (año) de los experimentos, hasta 2,6 t/ha en el cuarto, sugiriendo una respuesta fisiológica en los cultivos a la variable aplicación de N en el sistema NR. El N excedente en el cultivo, un estimado de N potencialmente perdido hacia el ambiente, fue 55% más bajo en el tratamiento NR comparado con el manejo convencional de N. Esta reducción en el excedente de N no fue tan grande como había sido anticipada, porque las concentraciones de N y la asimilación de N en la caña para la mayoría de los cultivos en todos los tratamientos fueron menores que aquellas previamente reportadas. Los resultados mostraron que sistema de reemplazo de N basado ecológicamente puede extraer (aprovechar) más la entrega ambiental sin reducción significativa de la producción. Los resultados mostraron también que la predicción de rendimiento del cultivo siguiente, una base común para el manejo del N, no es necesaria en caña de azúcar, siempre que las aplicaciones de N y la producción estén igualadas en el largo plazo.