Improved environmental outcomes and profitability through innovative management of nitrogen

Photo: Peter Thorburn November 2004

Peter Thorburn[1], Tony Webster[2], Jody Biggs[1], Ian Biggs[1], Sarah Park[3]

CSIRO Sustainable Ecosystems
[1]306 Carmody Rd St Lucia, Qld 4067
[2] PO Box 12139 Earlville BC, Cairns, Qld 4870
[3]GPO Box 284 Canberra, ACT 2601

Australian Government
Sugar Research and Development Corporation

CSIRO

Improved environmental outcomes and profitability through innovative management of nitrogen

SRDC Research Project CSE011

Final Report

Conducted by CSIRO Sustainable Ecosystems, Bundaberg Sugar, Mossman Agricultural Services Ltd, NSW Sugar Milling Cooperative and Maryborough Sugar Factory

Project Leaders:

Dr Peter Thorburn
CSIRO Sustainable Ecosystems
Queensland Bioscience Precinct
306 Carmody Rd
St. Lucia Qld 4067
Peter.Thorburn@csiro.au

Mr Mick Ward
Bundaberg Sugar
Muorilyan Mill
PO Box 77
Muorilyan Qld 4858

Mr Allan Rudd
Mossman Agricultural Services Ltd
PO Box 191
Mossman Qld 4873

Mr Rick Beattie
NSW Sugar Milling Cooperative
Broadwater Mill
117 Pacific Highway
Broadwater NSW 2472

Mr Peter Downs
Maryborough Sugar Factory
PO Box 119
Maryborough Qld 4650

The project participant/s wish to acknowledge receipt of project funding from the Australian Government and the Australian Sugarcane Industry as provided by the Sugar Research and Development Corporation.

Executive Summary

Nitrogen (N) fertiliser additions are an important contributor to productivity and profitability in intensive farming systems, including sugarcane production. However, applying N increases losses of N to the environment, and so all intensive agricultural industries face the challenge of maintaining productivity while minimising environmental impacts of N fertiliser use. This challenge has become particularly important for sugarcane production in Australia because community concern grows over the impact of N on the health of the Great Barrier Reef and sugarcane production has the largest use of N fertiliser in the region.

It has been suggested that replacing the N lost from a crop through harvested cane and environmental losses will better align N fertiliser applications to the actual needs of sugarcane crops and the other potential sources of N available to the crop, and so improve the financial and environmental sustainability of the Australian sugarcane industry. In this project we tested and further developed an innovative N fertiliser management system, the N Replacement (NR) system. The project consisted of six streams of research which, together with their main results are described below.

1. The amount of N lost from fields through harvested cane and (unavoidable) environmental losses is a fundamental parameter in determining N fertiliser additions. In this project we found that there was less N in harvested cane (~0.5 kg t^{-1} compared with 0.9 kg t^{-1}) than previously thought, although amounts in trash were similar. Thus N removed through harvesting (and burning) the crop is less than anticipated and so losses to the environment are greater. Because of the lower N in cane, N was lost to the environment will be greater than previously estimated.

2. The NR system proposes that replacing these losses provides a reliable and profitable cane supply. In 11 experiments yields were generally similar in the NR treatment and under farmers' conventional N management (NF), despite the fact that N applications were on average 64 kg ha^{-1} lower using in the NR treatments. We estimate that N lost to the environment was ~40% less than in NR treatment than the NF. There was a trend for yields in the NR treatments to be lower than those in NF in the first crop after the treatments were imposed, with yield either 'catching up' or exceeding those at higher N rates in later crops. This catch-up even occurred at a site where N in soil was deliberately run down prior to establishment of the NR treatment.

3. These results suggest that, if assessed over the medium- to long-term, the 'replacement rate' in the NR system (1 and 1.3 kg N t^{-1} in trash blanketed and burnt cane, respectively) provides a benchmark, for the industry and broader community, of the amount of N needed for sustainable sugarcane production.

4. Nitrogen contributions from organic sources, such as mill mud or fallow legumes, were shown to be greater, and last for more cane crops than previously thought. For example, fallow soybeans in Bundaberg or Mossman might supply adequate N for the following plant crop, and > 90%, 20-40% and ~10% of the N needs in each of the subsequent ratoons. Nitrogen supplies from legumes were lower in the Burdekin, being two thirds of those for the other two regions. Mill mud provides even more N, enough N to replace ~35% (or 275 kg ha^{-1}) of fertiliser N over the whole crop cycle. This reduction is equivalent to reducing of the 'replacement rate' from 1.3 to 1.0-0.8 kg N t^{-1} for burnt cane production and 1.0 to 0.7 kg N t^{-1} for a trash blanketed cane production.

5. Better management of N will be supported by widespread, cost effective monitoring of N stress in crops. We aimed to further develop and evaluate N in cane estimated with the widely adopted CAS-NIR system to provide such monitoring. CAS-NIR calibrations for cane N were greatly improved through the project. N in cane estimated by CAS-NIR was shown to have at least equal skill in detecting N stress as leaf testing, the current industry standard method. With both techniques, N stress was more accurately assessed comparing values against those from crops with known N deficiency or sufficiency, rather than predetermined benchmarks. Thus they are better as relative indicators than absolute ones. This concept needs to be explored further to determine how the best information can be obtained from both conventional leaf and NIR-estimated N stress.

6. Two national symposia (with a total of 39 papers delivered) and three 'high-level' industry workshops primarily organised by the project team, together with regular interaction with regional groups and

collaborating farmers helped develop a knowledge base to underpin adoption of the ‘replacement’ N management practices. Impacts have included early adoption of the NR system by farmers, it inclusion as an ‘A-Class’ practice in a number of Water Quality Improvement Plans, and independent testing of the system by BSES Ltd.

Background

It is well know that nitrogen (N) fertiliser additions are an important contributor to productivity and profitability in intensive farming systems (Neeteson, 1995), including sugarcane production (Keating *et al.*, 1997; Thorburn *et al.*, 2003a). However applying N increases losses of N to the environment, and so all intensive agricultural industries face the challenge of maintaining productivity while minimising environmental impacts of N fertiliser use (Eickhout *et al.*, 2006). Thus all intensive agricultural industries face the challenge of maintaining productivity while minimising environmental impacts of N fertiliser use. Recently these issues have become particularly important for sugarcane production in Australia as community concern grows over the impact of N on the health of the Great Barrier Reef and sugarcane production has the largest use of N fertiliser in the region.

Deciding how much N fertiliser to apply to any crop, including sugarcane, requires estimates of the likely crop yield and the amount of N needed to achieve that yield. Historically, the Australian sugarcane industry did not explicitly address these questions in developing N fertiliser recommendations. Recommendations were developed from empirical marginal response yield curves (e.g. Chapman, 1994) that resulted in very broad, industry-wide recommendations (Wood *et al.*, 1997). In the late 1990s there was a call for soil-based recommendations (following the South African approach; Meyer and Wood, 1994) based on mineralisation of N from soil organic matter (Wood *et al.*, 1997; Schroeder *et al.*, 1998). The result was the soil specific N recommendations of Schroeder *et al.* (2002) and Wood *et al.* (2003).

Soil-based N recommendations focus on the ‘supply’ of N to the crop, but the crop’s N requirement (i.e. the ‘demand’ for N) is equally important in determining N fertiliser management. In recognition of the importance of N crop’s demand, Thorburn *et al*. (2003a) developed the ‘N Replacement’ system of N management, in which N fertiliser applications were directly linked with crop yield. They used the yield of the previous crop to (implicitly) set expectation of the yield of the following crop. This approach contrasted many systems that used *potential* yield to determine crop’s N demand. The ‘N Replacement’ system was based on the assumption that the expected yield did not need to be precisely defined because soil N reserves could buffer the difference between expectations and the actual yield achieved for a single crop, provided, over the longer-term, N applied equalled the N removed in crop off-take plus N lost to the environment. In using actual yields rather than ‘potential’ yields, the NR system overcame the generally recognised problem of N applications being higher then needed for the crop yield actually achieved because yields are almost universally less than potential.

In developing the ‘N Replacement’ system, Thorburn *et al*. (2003a) also drew on studies of sugarcane N physiology (Muchow *et al.*, 1996; Wood *et al.*, 1996) and environmental losses of N (Thorburn *et al.*, 2003b; Stewart *et al.*, 2006) to estimate the N applications needed per tonne of sugarcane yield expected. Thus they set the framework for explicitly addressing the questions ‘how much cane will be grown?’ and ‘how much N will that cane need?’

Fertiliser is not the only source of N available for sugarcane crops. Legume fallows are a substantial source of N within the sugarcane cropping cycle. For example, the gross contribution of N from a well-managed crop of soybean can be over 300 kg ha^{-1} (Garside *et al.*, 1996). Thus the inclusion of a high yielding legume fallow within the sugarcane cropping cycle can both increase cane yield and enable farmers to eliminate or reduce N fertiliser applications to the subsequent sugarcane plant crop. Further, the Australian sugar industry produces around 2 million tonnes of mill mud each year (Barry *et al.*, 1998, 2001), much of which is applied to sugarcane fields. At typical application rates (~150 t ha^{-1} wet) mill mud may contain 500 kg ha^{-1} of nitrogen (N), roughly two thirds of the total amount of N fertiliser typically applied over a whole crop cycle. Where sugarcane is grown following a fallow legume or mill mud application, fertiliser N applications need to be reduced. So, regardless of the recommendation system used, N fertiliser requirements of crops need to account for N inputs from these organic sources. However, N in both legumes and mill mud is in organic form so will only be slowly available to sugarcane crops as the organic N is mineralised in the soil. There is little information of the time scale of these mineralisation processes, and hence little evidence to base recommendations on. So, N inputs from these sources have generally not been recognised in N fertiliser recommendations (Calcino, 1994).

A rational reaction by farmers to any uncertainty about N needed by crops is the addition of more N fertiliser. Potentially, the more closely aligned N fertilisation applications are to crops' requirements the more prudent it is to monitor crops for possible N deficiency. While leaf N analysis has been a widely promoted method of monitoring N status in sugarcane crops, there are other, potentially more cost-effective methods. In sugarcane the stem is the major storage organ for a range of compounds (including N) and the N status of the crop is reflected in the stem N concentration (reference?). All sugarcane grown for sugar production needs to pass through a sugar mill, so developing a method of measuring stem N at the mill potentially provides a universal, low cost means of generating information about potential N deficiency in the cane crop (Keating *et al.*, 1999; 2003). Near Infrared (NIR) analysis is a convenient tool for rapid in-line cane N monitoring of sugarcane material as it passes through the mill (Staunton *et al.*, 1999). However, to develop a mill-based monitoring and reporting system for cane N, we need to (1) establish how accurately stem N can be detected by CAS-NIR systems in the mill, and (2) develop predictive relationships between stem N and N stress in sugarcane. This paper focuses on advances in monitoring cane N with CAS-NIR.

In summary, there are potentially innovative ways of managing N fertiliser that will better align N fertiliser applications to the actual needs of sugarcane crops and the other potential sources of N available to the crop, and so improve the financial and environmental sustainability of the Australian sugarcane industry. These management recommendations can be supported by more widespread, cost effective monitoring of crop N status to increase confidence that N fertiliser applications are at the optimum for industry sustainability.

Objectives

The overall objective of this project is to reduce N fertiliser applications on sugarcane farms to decrease production costs to farmers and abate N losses to the environment. This objective will be achieved through developing and implementing the 'N Replacement' concept of N management by:

1. Better defining the amount of N lost through harvested cane, trash burning (where applicable) and unavoidable environmental losses in different regions (from the wet tropics to NSW), under different conditions (e.g., irrigation and dryland) and different farm management practices (e.g. fertiliser type, N application technique).

2. Demonstrating that replacing these losses provides a reliable and profitable cane supply.

3. Developing methods for accounting for N contributions from organic sources, such as mill mud or fallow legumes, to sugarcane N supply.

4. Applying and refining in-mill and other methods of monitoring the N status of sugarcane crops.

5. Developing the knowledge base within the farmer and advisor community to underpin adoption of the 'replacement' N management practices.

6. Defining benchmarks, for the industry and broader community, of the amount of N needed for sustainable sugarcane production.

All objectives in the project were achieved.

Methodology and Results

N Replacement field experiments

Field experiments (Table 1) were established to address the first two objectives of this project (more complete details given in Attachment 1). Data collected in the experiments were used define the amount of N lost through harvested cane and trash burning (where applicable), and so allowed the estimation of environmental losses of N. The experiments also tested whether the 'N Replacement' concept could provide a reliable and profitable cane supply.

Table 1. Details of the experimental sites.

Site code	Region	Texture (0-0.6 m)	Total C[a] (0-0.3 m)	C/N[a] (0-0.3 m)	Variety	Reps
One-year crops						
BK-1	Burdekin	sandy clay loam	0.77	14.2	Q96 & Tellus	2
BK-2	Burdekin	sandy clay loam	0.84	15.3	Q117	2
BU-1	Bundaberg	sandy loam to sandy light clay	0.75	14.8	Q138	3
CD-1	Condong	light clay	2.03	13.5	Q151	2
IN-1	Innisfail	sandy clay	1.87	17.9	Q187	3
IN-3	Innisfail	light clay	2.16	16.6	Q186	1
MB-1	Maryborough	light clay	1.21	17.8	Q135	1
MB-2	Maryborough	sandy clay loam	1.12	18.9	Q138	3
ML-1	Mulgrave	sandy clay	1.17	16.9	Q200	1
MS-1	Mossman	sandy clay	1.22	13.4	Q174	3
MS-4	Mossman	light clay	1.24	14.3	Q175	1
Two-year crops						
BW-1	Broadwater	clay loam	2.34	12.4	RB72-454	2
BW-2	Broadwater	light clay	1.69	12.2	Q124	2
HW-1	Harwood	clay loam	2.05	13.2	Q136	2
HW-2	Harwood	clay loam	2.56	12.7	Empire	1

[a] Soil C and N concentrations determined by combustion with a LECO CNS analyser.

In 11 of the experiments, all one-year crops, yields in the NR treatment were similar to those achieved with the farmers' conventional N management (Figure 1) which had average N applications 18 to 157 kg ha^{-1} greater than in the NR treatments (Table 2). In four sites with two-year crops in NSW, N rates for NR were similar to or greater than the farmer's current N applications (Table 3) and yields in the NR treatment were similar to those at higher N rates (Figure 2).

Table 2. Average N rates (kg ha^{-1}) applied in N fertiliser and, at sites BK-1 and BK-2, irrigation water in the different treatments (NL- Low; NF- Farm; NR- Replacement) at the sites with one-year crops.

Site code	NL[a]	NR[b]	NF[b]	Diff between NF & NR	Diff between 6 Easy Steps & NR
BK-1		159	318	160	52
BK-2		217	326	109	-17
BU-1	35	95	140	45	55
CD-1	67	143	146	6	na[c]
IN-1	68	88	168	80	32
IN-3		117	144	27	3
MB-1	63	128	160	32	2
MB-2	55	111	152	41	29
ML-1		135	180	45	5
MS-1		95	177	82	35
MS-4		93	174	82	38

[a] Treatment not established at all sites.
[b] "NR" = replacement and "NF" = Farmers' usual N rate.
[c] There are no 6 Easy Steps recommendations published for NSW mill areas

In the one-year crops (Figure 3), cane N concentrations were variable between sites, 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 2). There was little difference in N concentrations in cane from the NR and NF treatments at seven of the 10 experiments, the 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.

N concentrations and N uptake in cane in most experiments were considerably lower than those previously reported (Muchow *et al.*, 1996; Wood *et al.*, 1996). This unexpectedly low N requirement explains why yields were maintained with the lower N applications in the NR treatments. The lower N concentrations also meant that the crop N surplus (i.e. fertiliser N minus the N removed at harvest) was greater than expected. The results also show that it is not critical to accurately predict the yield of the coming crop in developing an N management strategy, provided N applications and production are matched in the longer term. We suggest that focussing on the minimum surplus needed to maintain productivity and soil N reserves may usefully guide future thinking on sustainable N fertiliser management.

Table 3. Average N fertiliser rates (kg ha^{-1}) applied in the different treatments (NL- Low; NF- Farm; NR- Replacement; NH- High) at the sites with two-year crops.

Site code	**NL**	**NF[a, b]**	**NR[a]**	**NH[b]**
BW-1	150	223	303	
BW-2	140		220	260
HW-1	161		212	252
HW-2	173		200	230

[a] "NR" = replacement and "NF" = farmers' usual N rate.
[b] Treatments not established at all sites.

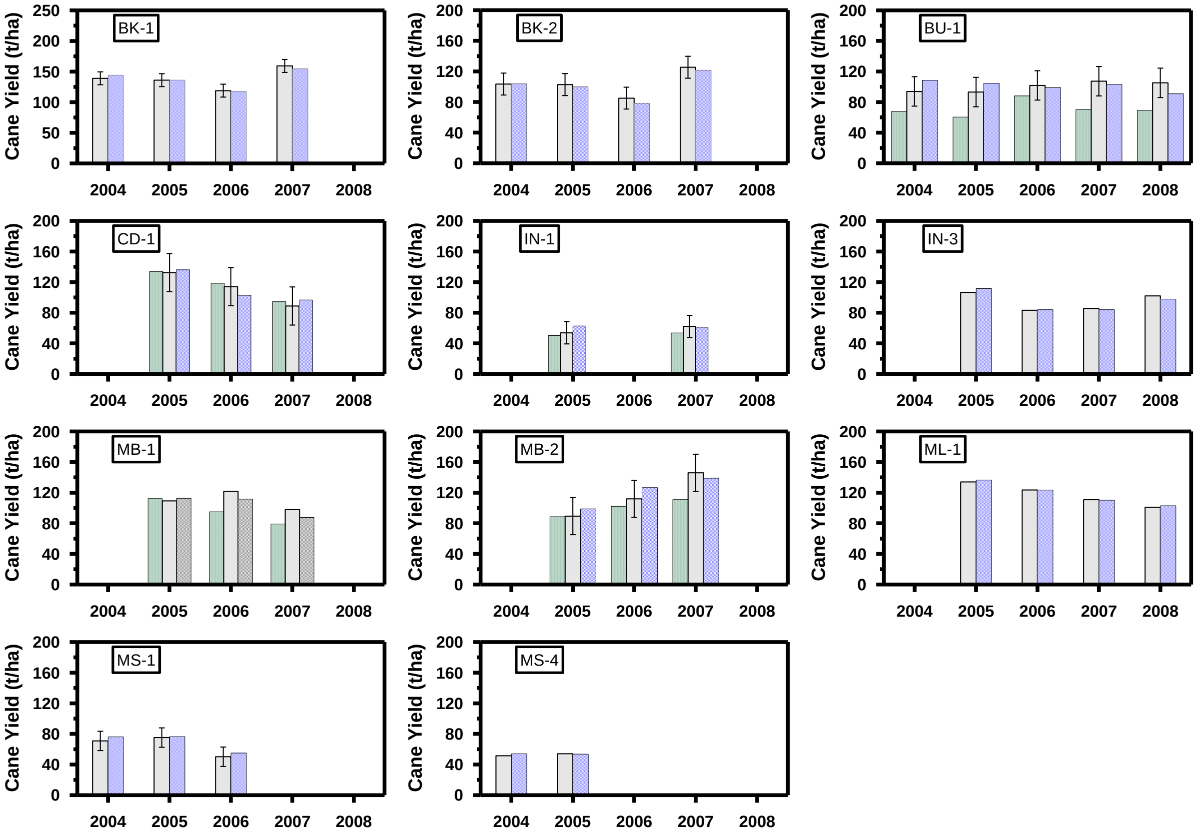


Figure 1. Cane yields of one-year sugarcane crops harvested from on-farm experiments comparing the N Replacement treatment (NR, grey bars) with farmers' conventional N fertiliser management practice treatment (NF, blue hatched bars) and, at some sites, a treatment with a lower rate of applied N (NL, green

stippled bars). In replicated experiments errors bars indicate the critical difference for comparing between treatments. Note: there are no results for site IN-1 in 2006 due to cyclone damage.

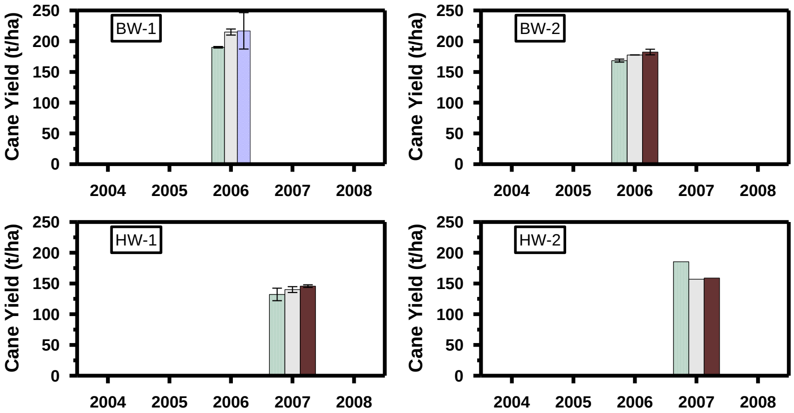


Figure 2. Cane yields of two-year sugarcane crops harvested from on-farm experiments comparing the treatment described in Figure 1 and one with a higher rate of N (brown bars). Error bars indicate the range of yields for sites with replicate plots.

Benchmarks of the N needed for sustainable sugarcane production

These results suggest that, if assessed over the medium- to long-term, the 'replacement rate' (1 and 1.3 kg N t^{-1} in trash blanketed and burnt cane, respectively) provides a benchmark, for the industry and broader community, of the amount of N needed for sustainable sugarcane production.

N contribution from organic sources

Nitrogen in organic sources needs to mineralise to become available to plants. Mineralisation is affected by the quality of the organic matter, and the environment (temperature, moisture) in which mineralisation occurs. There is a long history of examining mineralisation in laboratory conditions of constant temperature and moisture. The question then is how to make this knowledge relevant to field conditions? The understanding derived from laboratory studies has been captured in N and C cycling models. These models can then be applied with climate data to estimate the mineralisation, and hence availability of organic N to plants **under field conditions**.

In this section of the project, we used the N and C cycling capability of the APSIM sugarcane model (Thorburn *et al.*, 2005) to determine the contribution of organic N in fallow legumes or mill mud to the N needs of sugarcane and hence address Objective 3 of the project. Initially we developed capability in APSIM to (1) simulate growth and development of tropical soybeans commonly planted in sugarcane fallows in the APSIM 'legume' module, and (2) simulate mill mud in the APSIM 'surface organic matter' module. We then simulated how N fertiliser inputs might be adjusted to account for N becoming available from legume (Attachment 2) or mill mud (Attachment 3). We then undertook a limited number of field experiments to verify these predictions.

Availability of N from fallow legumes

APSIM has been widely used to simulate N cycling in wide range of cropping systems containing legumes (Carberry *et al.*, 1996; Probert *et al.*, 1998). However, tropical varieties of soybean commonly grown in sugarcane fallows, e.g. the variety Leichhardt, have not been simulated previously. Defining parameter values required estimating thermal time (i.e. the number of day degrees, ^{o}Cd) in each phenological stage of the plant's development. So model parameters for Leichhardt (Table 4) were determined using observed data collected from 28 soybean breeding trials conducted at Ayr and Walkamin over the period 2000-2007.

We then conducted field and simulation experiments to determine how long soybean N remains available to the sugarcane crop after a soybean break crop. A soybean and sugarcane rotation trial was carried out at

Mossman, Queensland over 22 months during which crop yield, plant N, and total soil C and mineral N were measured. The soybean variety Leichhardt produced 9 t ha^{-1} (s.e. 0.7) above ground dry weight, containing 301 kg N ha^{-1} (s.e. 36) which contributed to the soil N stores. Model predictions of the experiment over-estimated soybean biomass and N content by 22% and 24%, respectively. Sugarcane growth was simulated well, with predicted above ground fresh weight under-estimated by only 6%, with N content over-estimated by 18%. Simulations of the soybean crop model predictions explained 89% of the variation observed in soil mineral N to a depth of 150 cm.

Table 4. Parameter values used to simulate the growth of soybean variety Leichhardt expressed as thermal time (^{o}Cd). Thermal time requirement for end of juvenile phase to floral initiation depends on the duration of the photoperiod (within the range 11 to 17 hours).

Phenological stage parameter	**Thermal time (^{o}Cd)**
Emergence to end of juvenile phase	60
End of juvenile phase to floral initiation	700-2000
Floral initiation to flowering	24
Flowering to start grain fill	270
Start grain fill to end grain fill	900
End grain fill to maturity	40
Maturity to ripe	5

Long-term legume and sugarcane rotation systems were then simulated for the Mossman (one soil type), Burdekin (four soils) and Bundaberg (one soil) sugarcane regions. Across all three regions the simulations suggested that legume N was available to the sugarcane crop up to the fourth ratoon (Figure 3). Simulated reductions in fertiliser N application in the plant crop were 100% in Bundaberg and Mossman, consistent with industry recommendations (Schroeder *et al.*, 2007, 2008). But they were only 60-80% in the Burdekin region. Regional differences persisted in the first ratoon, with reductions in N of > 90% in Mossman and Bundaberg, and 40-60% in the Burdekin. Regional differences were less pronounced in later ratoons, with reductions in N of 20-40% in the second ratoon and ~10%, probably a negligible amount in practice, in the third ratoon. New fertiliser application regimes would require N management recommendations to be refined to avoid unnecessary financial and environment losses.

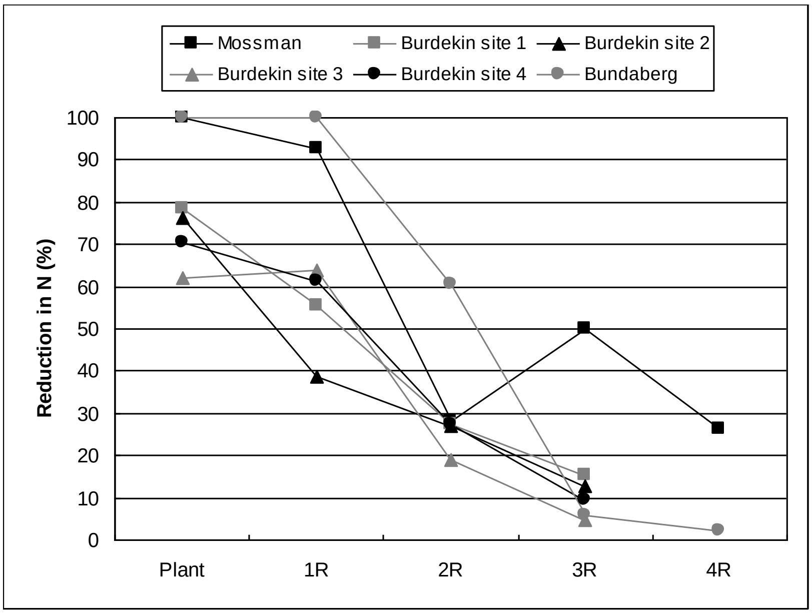


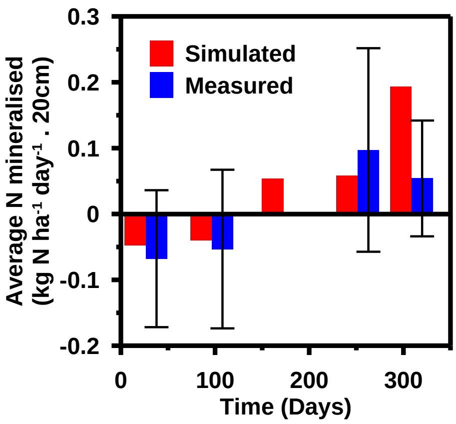
Figure 3. Comparison of simulated reductions in N fertiliser possible following a legume fallow. Long-term simulations were performed across different biophysical conditions and crop management practices. R = ratoon.

Availability of N from mill mud

This study consisted of four activities: We, (1) measured N mineralisation in soils following mill mud applications and verified the ability of APSIM to simulate this mineralisation, (2) conducted a survey of mill mud quality in the industry, (3) measured the effect of mill mud on soil N availability and productivity in field experiments, and (4) predicted the impact of N in mill mud on crop fertiliser N requirements and possible changes to the N Replacement concept.

Activities 1 to 3 showed that N in mill mud can be immobilised immediately following the application of mill mud, and that it can take 6 months or longer for there to be net mineralisation, and hence increased plant-availability, of N from mill mud. These soil N cycling process were able to be simulated accurately by the APSIM model (Figure 4). The extra N from mill mud can replace N from fertiliser, such that cane yields are maintained at lower N fertiliser applications following the application of mill mud.

Figure 4. Net nitrogen mineralised due to mill mud only (mineralisation due to soil has been removed) represented against days after mill mud application. Red bars representing APSIM simulation of this mineralisation. Error bars represent 95% confidence.



Simulations were undertaken identify the long-term implications of mill mud applications for N fertiliser management for two contrasting combinations of soil, climate, irrigation and tillage managements; i.e. typical crop management systems for the Maryborough and Burdekin regions. The simulations aimed to quantify the reduction in N fertiliser required to maintain productivity by comparing simulated N response curves, with and without mill mud applied, over a range of N fertiliser application rates. In all simulations mill mud was applied as a single application of 130 t_{wet} ha^{-1}, either at the beginning or middle (after harvest of the 1st ratoon) of the crop cycle to see if the time of application had any impacts on productivity. Response curves were also simulated for a range of mill mud C:N ratios.

Adding mill mud reduced the amount of N fertiliser needed to achieve maximum yield (averaged over all crops within a crop cycle) by ~35% in both the Maryborough (Figure 5) and Burdekin (Figure 6) simulations. The timing of application within the crop cycle, before either the plant or second ratoon crop, did not affect the outcome. Varying C:N ratio of mill mud had a relatively small impact on simulated crop N response (data not shown), although the reduction in N fertiliser requirements tended to be greater at lower C:N ratios (~22).

The implication of the results for N fertiliser management in these simulations is a saving of approximately 275 kg ha^{-1} of fertiliser N, over the whole crop cycle. In terms of the N Replacement concept, where the rate is determined based on past yields, the change is equivalent to a reduction of the ‘replacement rate’ from 1.3 to 1.0 kg N t^{-1} for a burnt system as simulated for the Maryborough. For a furrow irrigated system as found in the Burdekin simulations the NR rate would drop from the suggested 1.3 kg N t^{-1}, for a burnt trash system, to 0.8 kg N t^{-1}. Applying these reductions to trash blanketed cane production gives a reduction of the ‘replacement rate’ from 1.0 to 0.7 kg N t^{-1}.

If these results are found to be true in practice, there are considerable increases in profitability available to sugarcane farmers. However, the potential reduction in N fertiliser over the whole crop cycle (~275 kg ha^{-1})

is less than the total N contained in the applied mill mud (~500 kg ha^{-1}). Thus, even with more precise N fertiliser management, applications of mill mud may still be adding N to the cropping system. The fate of this N should be of concern as it could be lost to the environment in the longer-term.

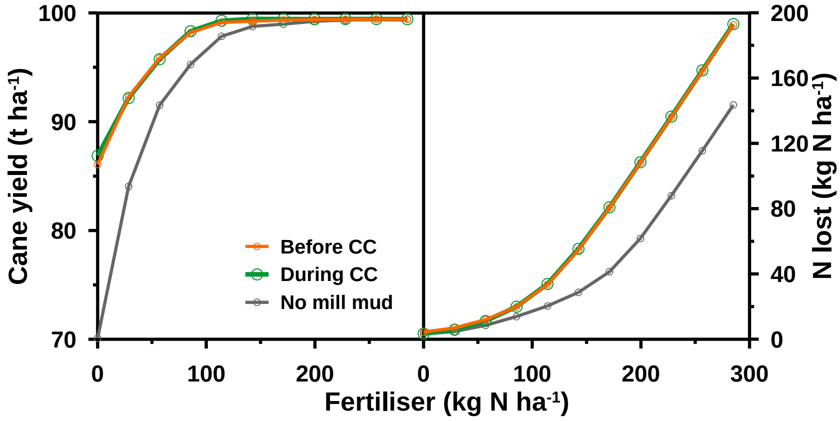


Figure 5. Long term simulated average cane yield and total N lost (incl. denitrification, run-off and deep drainage) for a typical Maryborough soil and management with mill mud not applied (No mill mud) or applied before the planting (Before CC) or applied after the harvest of the 1st ratoon (During CC).

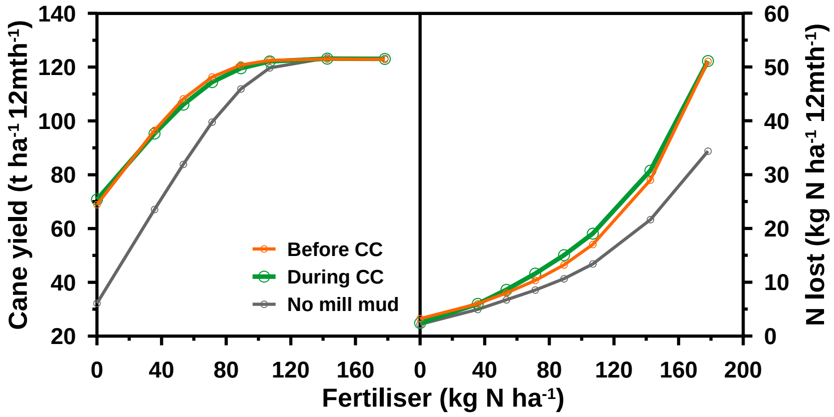


Figure 6. Long term simulated average cane yield and total N lost (incl. denitrification, run-off and deep drainage) for a typical Burdekin soil and management with mill mud not applied (No mill mud) or applied before the planting (Before CC) or applied after the harvest of the 1st ratoon (During CC).

In-mill methods of monitoring the N status of sugarcane crops

In sugarcane the stem is the major storage organ for a range of compounds, including N. So the N status of the crop, e.g. N deficiency, is reflected in the stem N concentration. All sugarcane grown for sugar production needs to pass through a sugar mill, so developing a method of measuring stem N at the mill potentially provides a universal, low cost means of generating information about potential N deficiency in the cane crop (Keating *et al.*, 1999; 2003). Near Infrared (NIR) analysis is a convenient tool for rapid in-line cane N monitoring of sugarcane material as it passes through the mill (Staunton *et al.*, 1999). However, to develop a mill-based monitoring and reporting system for cane N, we need to (1) establish how accurately stem N can be detected by CAS-NIR systems in the mill, and (2) evaluate the relationship between CAS-NIR detected stem N and N stress in sugarcane. To address Objective 4 of this project, we focussed on developing better calibration of CAS-NIR for monitoring cane N in sugar mills and the subsequent evaluation of the presence or absence N stress in cane from that information, in comparison with other N stress indicators.

CAS-NIR calibration

CAS-NIR was calibrated developed from total N concentrations of fibrated cane collected each year at the Mossman and Maryborough sugar mills form 2005 to 2007, and the Tully, Condong, Broadwater and Harwood mills in 2007. There are two types of CAS-NIR instruments in Australia sugar mills. The Mossman and Tully mills have ‘Type 2’ instruments, while the other four mills included in this study have ‘Type 1’ instruments. Separate calibration equations were able to be developed each instrument type (Table 5). These calibrations (R^2 > 0.85) are a considerable improvement over those that existed prior to the project (R^2 ~0.5).

Table 5. Calibration statistics for global total N calibration equations for the two types of CAS-NIR machines in Australian sugar mills: SEC is standard error of calibration = $(\sum(x\text{-}y)^2 - \{[\sum(x\text{-}y)]^2 / N\}/N\text{-}1)^{½}$; R^2 is the correlation coefficient; Mean is mean of the total N values in the calibration equation; SD is standard deviation of the total N values in the calibration equation; Range is the effective range of total N values the calibration equation can detect; n is the number of samples the calibration equation uses in development; RPD is the ratio of standard error to the standard deviation =SD/SEC; CV is the coefficient of variation = (SD x 100)/Mean; RER is the ange error ratio = ratio of SEC to the reference data range.

Instrument Type	Calibration Statistics SEC	R^2	Mean	SD	Range	N	RPD	CV	RER
Type 1	0.03	0.86	0.22	0.07	0.07 - 0.48	329	2.5	13.6	13.7
Type 2	0.02	0.89	0.18	0.04	0.10 - 0.43	125	2.2	11.1	20.5

N stress indicators

To be useful in supporting N fertiliser management decisions, N stress indicators need to detect when a crop is suffering, or has suffered, N stress. N stress in this context is defined as the yield was limited by supply of N fertiliser, i.e. if more fertiliser was applied to the crop the yield would have increased. N stress indicators are thus ideally evaluated against N fertiliser rate experiments, where yields and N stress indications are measured across different rates of N fertiliser. We evaluated a number of N stress indicators over the different treatments at the field experiments established in this project where cane N was able to be measured at the mill by CAS-NIR.

While CAS-NIR determined cane N concentration may be a convenient N stress indicator for the reasons given above, it is not the only one available for application in the Australian sugar industry. N concentrations were also measured in hand-harvested cane by conventional laboratory techniques. This measurement should give a more direct measure of stem N than the CAS-NIR as the possible complications of calibration equations and extraneous matter contaminating the cane supply are eliminated. Leaf N was also measured (according to standard techniques; Schroeder *et al.*, 1999) as it is the industry standard N stress indicator. A leaf N concentration below 1.8% indicates N stress (Schroeder *et al.*, 1999).

Hand-harvested cane N concentrations (referred to as ‘stem N’), CAS-NIR N determined cane N concentration (referred to as ‘NIR N’), and leaf N were evaluated against yield response across different N treatments. Relative to yield response, an indicator can have one of three possible results: Firstly, they correctly indicate the presence or absence of N stress. That is they either indicate that there is N stress and there is a yield response to increasing N applied, or they indicate no N stress and the yields do not increase with increasing N applied. Secondly, they can indicate N stress but there is no yield response (a false positive). And thirdly, they fail to indicate N stress but a yield response does occur (a false negative).

We interpreted differences in stem N between treatments as meaningful when they were greater than 30%. Differences in CAS-NIR N or leaf N between treatments were interpreted as meaningful when there was greater than 15% change. For example, at site MB-1 in 2005 (Figure 7) there is no yield difference between the three treatments. Thus the yields in the NL and NR treatments, which received less N fertiliser than the NF treatment, can not have been limited by N fertiliser supply. The stem N concentration did not differ between the NL and NR treatments, indicating a correct prediction. However, the stem N concentration increased by 143% from NR to the NF treatment suggesting the crops in the NR treatment were N stressed, but this increase was not reflected in the yields so the prediction of N stress was false in this case. Thus the stem N concentrations provide a false positive outcome in this instance. For NIR N, the concentrations did not vary between the three treatments indicating correct predictions. The leaf N concentrations were also similar across all three treatments suggesting, correctly, no differences in N stress (and hence yield). In addition, the absolute leaf N concentrations are all higher than the critical leaf N concentration of 1.8%, indicating there will be no yield response above the NL treatment, which is also a correct prediction.

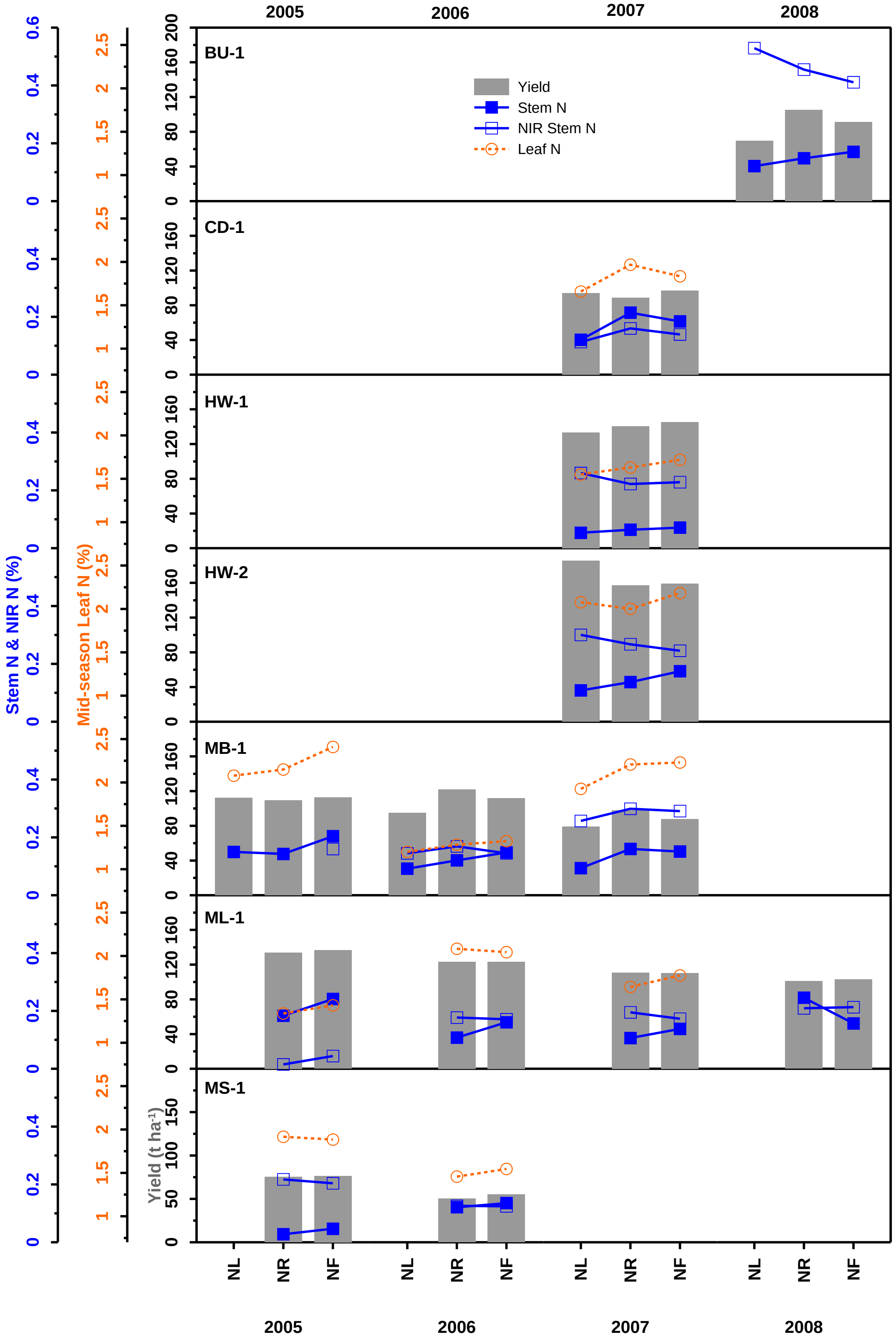


Figure 7. Comparison of N in stems (in blue, measured by both conventional laboratory methods and CAS-NIR), cane yields (grey), and leaf N (orange) of sugarcane across different N fertiliser treatments from seven large-scale field experiments.

We undertook similar assessments of N stress from stem N, CAS-NIR N and leaf N relative to measured yield response for all the data in Figure 7. There were 24 cases where stem N could be compared against yield, 18 instances for NIR N, and 17 for leaf N (Table 6). Stem N and NIR N gave correct predictions in 67 and 83% of cases, respectively. When assessed against the absolute threshold of 1.8%, leaf N determined N stress correctly in only 59% of cases. When used as a relative indicator (i.e., changes in concentration between treatments) however, leaf N predicted N stress correctly in 88% of cases.

Table 6. Predictions of N stress from relative change in stem N, CAS-NIR N, leaf N and absolute leaf N concentrations compared to yield responses across different N treatments in seven field experiments. [green] = correct prediction of yield response [red] = false positive prediction of yield response [yellow] = false negative prediction of yield response [black] = no data. NB: three independent data sets were available at the BU-1 site.

Site/Year	Relative Stem N		Relative CAS-NIR N		Relative Leaf N		Absolute Leaf N	
	NL-NR	NR-NF	NL-NR	NR-NF	NL-NR	NR-NF	NL-NR	NR-NF
BU-1 (1)	[yellow]	[green]	[yellow]	[green]	[black]	[black]	[black]	[black]
BU-1 (2)	[green]	[green]	[black]	[black]	[black]	[black]	[black]	[black]
BU-1 (3)	[green]	[red]	[black]	[black]	[black]	[black]	[black]	[black]
CD-1	[red]	[green]	[red]	[green]	[red]	[green]	[red]	[green]
HW-1	[green]	[green]	[green]	[green]	[green]	[green]	[red]	[red]
HW-2	[green]	[green]	[green]	[green]	[green]	[green]	[green]	[green]
MB-1 05	[green]	[red]	[black]	[black]	[green]	[green]	[green]	[green]
MB-1 06	[green]	[red]	[green]	[green]	[yellow]	[green]	[green]	[red]
MB-1 07	[green]	[green]	[green]	[green]	[green]	[green]	[red]	[green]
ML-1 05	[black]	[red]	[black]	[red]	[black]	[green]	[black]	[red]
ML-1 06	[black]	[red]	[black]	[green]	[black]	[green]	[black]	[green]
ML-1 07	[black]	[green]	[black]	[green]	[black]	[green]	[black]	[red]
ML-1 08	[black]	[green]	[black]	[green]	[black]	[black]	[black]	[black]
MS-1 05	[black]	[red]	[black]	[green]	[black]	[green]	[black]	[green]
MS-1 06	[black]	[green]	[black]	[green]	[black]	[green]	[black]	[green]
Correct	16/24 (67%)		15/18 (83%)		15/17 (88%)		10/17 (59%)	

The results show that NIR N has the potential to be as good an indicator of crop N stress as leaf N (the current industry standard) and hand-sampled stem N (a more direct measurement of N in cane). NIR N and stem N were assessed relative to concentrations in different N treatments, and not against a critical value. This was done as critical values have not been determined yet for these parameters yet. However, leaf N performed better as a relative indicator of N stress than an absolute one. Leaf N concentrations are know to be affected by factors other than N supply (Schroeder and Barnard, 2002) and, presumably, comparing leaf N across different N treatments may be accounting for the impact of these external influences. Thus, the Australian sugar industry may get added accuracy from leaf N analysis if plots with different N supply were established in regions to provide reference values for leaf N tests. Stem N and NIR N varied substantially across different sites. Thus it is possible that cane N concentrations, like leaf N, are affected by factors other than N supply. If this is true, it suggests that establishing critical values for these parameters may provide little value. Effort may be better concentrated on establishing the processes required to have reference plots widely established to provide reference values for interpreting information gained from farmers' cane blocks. Given that information can be obtained for every block in a region where mills have CAS-NIR installed, there could be considerable value is establishing such a system.

Developing the knowledge base to underpin adoption of N Replacement

Three specific activities were undertaken to develop a more robust knowledge base on N cycling in sugarcane systems, to support changes in N management practices, including the N Replacement approach. These activities were conducting national symposia, conducting high level industry workshops and ongoing contact with regional groups and collaborating farmers. Details of these activities follow.

In addition to these activities, project results were published where ever possible (see List of Publications, below), resulting in 16 papers and abstracts published during the project and a further paper submitted for publication.

National N symposia

Two national symposia were organised with a total of 39 papers delivered (Tables 7 and 8). The first, in May 2006, was a one day symposium help at the University of Queensland Bioscience Precinct. The symposium was attended by approximately 60 people. The second symposium was 'embedded' in the Australian Society of Sugar Cane Technologists 30th conference, held in Townsville, May 2008. Topics at both symposia ranged from fundamental soil-plant processes, management of N fertiliser and water quality and other environmental impacts. These symposia focused on N cycling, and also provided a broader coverage of related issues than would have otherwise occurred.

Table 7. Presentations at the 2006 Nitrogen Symposium.

Topic	Speaker/s
Plant and soil processes	
Improving nitrogen use efficiency (NUE) of sugarcane: acquisition efficiency of N sources	Suzanne Schmidt
Improving nitrogen use efficiency (NUE) of sugarcane: internal efficiency and breeding	Andrew Fletcher
The availability of N from sugarcane trash on contrasting soils in the wet tropics of North Qld	Elizabeth Meier
Greenhouse gas emissions from sugarcane soils and nitrogen fertiliser management	Tom Denmead
Concepts in managing N fertiliser 1	
Enhanced Nitrogen R&D Extension Services	Martin Shafron
The modified nitrogen management guidelines	Bernard Schroeder
Soil reference sites - a basis for best-practice nutrient management	Bernard Schroeder
Pedotransfer functions for assessing mineralisation potential of sugarcane soils	Phil Moody
Current and proposed nitrogen experimentation in the Bundaberg, Herbert and Mackay regions	Andrew Wood
Hazard and Risk Decision Support Systems for N Management at Block Scale	Phil Moody
Delivering the modified nitrogen guidelines to industry	Barry Salter
Concepts in managing N fertiliser 2	
The N replacement concept: A potential innovation in sustainable nitrogen fertiliser management	Peter Thorburn
Field testing the N replacement concept	Tony Webster
Characterising N release form organic sources: I Fallow legumes	Sarah Park
Characterising N release form organic sources: II Mill mud	Jody Biggs
Monitoring N stress in sugarcane: Approaches at the mill	Ian Biggs
Water quality in irrigated areas	
Deriving nitrogen balances in conventional & new cane farming systems	Peter Stork
A farmers approach to nitrogen management	Tom McShane
Sustainable irrigation in the Burdekin: Losses of farm chemicals in runoff and deep drainage	Steve Attard
Economic evaluations of water quality BMP's in the Burdekin	Peter Roebeling
Water quality in the wet tropics	
Surface losses of nitrogen in stormwater from sugarcane cultivation in the Wet Tropics	Jon Brodie
Economic evaluation of BMP's for water quality improvement in the Douglas shire	Peter Roebeling
Water quality monitoring in the Herbert	Tim Wrigley

Table 8. Presentations at the Nitrogen Symposium conducted within ASSCT 2008.

Topic	Author/s
N and water quality	
A policy framework for sustainable fertiliser use and management.	MC Shafron
The reef water quality partnership: a pathway to delivery.	J Waterhouse, R Eberhard
Development of 'ABCD' nutrient management framework for water quality improvement at regional scale.	W Higham, J Drewry, C Mitchel
Farming practices to meet the water quality challenge in the Burdekin region.	SJ Attard, PJ Thorburn, JS Biggs, J Kemei, T Anderson
N replacement: a simple approach to improving nitrogen use efficiency in sugarcane.	AJ Webster, PJ Thorburn, JS Biggs, IM Biggs, MF Spillman, SE Park
Concepts in managing N fertiliser	
Nitrogen balances in sugarcane farming systems as affected by nitrogen fertiliser applications.	PJ Thorburn, AJ Webster, JS Biggs
A comparison of different approaches for deriving nitrogen application rates using trial data from Macknade.	BL Schroeder, AW Wood, PW Moody, JH Panitz
The use of replicated strip-trials for demonstrating the effectiveness of different nutrient management strategies for sugarcane.	B Salter, BL Schroeder, AW Wood, JH Panitz, G Park
Research aimed at enhancing nitrogen management guidelines for the six easy steps program.	AW Wood, BL Schroeder, AP Hurney, B Salter, JH Panitz
Organic sources of N	
Impacts of crop rotation, tillage and N fertiliser applications on cane growth and N dynamics in the Bundaberg region.	MJ Bell, NV Halpin, GR Stirling, PW Moody, AL Garside
Adapting sugarcane nitrogen management practices to take account of legume fallows.	S Park, H Horan, T Webster, I Biggs, J Biggs, P Thorburn
Potential impacts of mill mud on nitrogen fertiliser requirements for sugarcane production.	PJ Thorburn, SE Park, P Bloesch, AJ Webster, HL Horan, IM Biggs, JS Biggs
Gaseous losses	
Emissions of nitrogen gases from sugarcane soils.	OT Denmead, BCT Macdonald, T Naylor, B Salter, S Wilson, DWT Griffith and D Chen
The impact of trash blankets on denitrification.	JS Biggs, PJ Thorburn, ME Probert
N physiology	
Monitoring nitrogen stress in sugarcane: Approaches at the mill using total N.	IM Biggs, AJ Webster, PJ Thorburn, S Staunton, JS Biggs
An integrated approach to reducing N inputs in Australian sugarcane farming systems.	N Robinson, A Whan, A Fletcher, K Vinall, R Brackin, P Lakshmanan, S Schmidt

Industry workshops on N management

The second activity consisted of three facilitated industry workshops, conducted in May 2006, 2007 and 2008. These workshops provided a forum to explore, in detail, the different approaches to management N fertiliser available to the Australian sugar industry. The detail included discussions on the strength/weaknesses and overlaps/inconsistencies of the different approaches, and recommendations for further development of N recommendation systems that could best help farmers and the industry with their N fertiliser management practices. Key representatives from the different sectors of the industry (farmers, CANEGROWERS, millers, fertiliser industry, extension and research staff from relevant organisations) were invited to the workshops, and there was considerable consistency in attendance over the three workshops.

The first workshop tended to provide more background information on the approaches, with more detailed discussions happening in the second and, especially, third workshop. Hence the outcomes and recommendations from the third workshop are the most detailed. A key message that came from farmers was that it is important for farmers (and their advisors) to be aware of the current N management options, and that the details of the different options should be made available to them so that individuals can decide which is appropriate for their circumstances. For example, 'early adopters' should be able to choose a different scheme from the majority of farmers. This key message formed the first of many recommendations devised at the third workshop. These recommendations were:

1. Provide additional detail in SIX EASY STEPS manuals to allow farmer/advisor greater flexibility to determine their N rate. This detail could take the form of a 'two page' description describing:
   a. The flexibility that can be used in interpreting a target yield when making recommendations with SIX EASY STEPS. Options include defining reference yield based on regional average yields (as in current manuals) or based on a more realistic block specific yield (similar to that presented in the NR concept).
   b. The possible variations in N requirements of sugarcane (e.g. 1.4 kg t^{-1} for the first 100 t ha^{-1} grown in SIX EASY STEPS, or 1 kg t^{-1} for GCTB system used in the NR system).
2. Develop a flexible framework (e.g., a software tool) to facilitate individual farmers choosing their expected yield and the amount of N needed (per tonne of cane) to achieve that.
3. Initiate research to address the knowledge gaps identified above, especially demonstration of the relationship between reduced N fertiliser applications and reduced environmental losses of N.
4. Look for links to precision agriculture as a technology to facilitate improved N management.
5. Look for a diverse range of sources to fund these activities.

The full workshop report is given in Attachment 4.

Regional groups

Groups were established in the Mossman, Innisfail-Babinda and Maryborough regions to provide a local forum for discussing project aims and results, and the underpinning processes of N cycling and N fertiliser management. The groups met at least twice each year and consisted of local farmers, extension staff (from BSES Ltd and/or productivity boards) and mill representatives. The composition of the groups remained reasonably constant throughout the project and members of the group became quite conversant with the project. The change in knowledge of group members was evaluated, as described below in the outcomes section.

In the Burdekin region, the discussion forum utilised the established Cane Productivity Initiative (CPI). Project aims and results were presented either as part of general CPI meetings or at dedicated meeting. This method of interaction with farmers provided contact with a large number of farmers in the region. Extension staff (from BSES Ltd and/or productivity boards), in particular, gained a good understanding of the concepts being tested which led to a positive outcome (described below).

In NSW, because of the distances involved between the three mills regions (Condong, Broadwater and Harwood), it was not feasible to have regional groups. Instead, there were detailed interactions between the project team and regional extension officers. The extension officers are now in a position to include relevant aspects of the N replacement systems in their local N fertiliser recommendations.

Intellectual Property and Confidentiality

There are no issues relating to intellectual property in this project. We request that draft publications attached to this report not be made public without the authors' permission.

Environmental and Social Impacts

The results of this project suggest that the amount of N that is lost from sugarcane crops to the environment, are currently in the order of 0.8 kg t^{-1} cane. If proved successful on wider testing, adoption of the N replacement system could reduce these surpluses by 0.3 kg t^{-1} cane, or 10,000 t of N per year across the whole industry. This amount of N is equivalent to the annual N loads currently flowing to the Great Barrier Reef in three major rivers. As well as providing financial savings of over $10M per year, the reduced environmental impact could significantly enhance the public's perception of the industry's provision of ecosystem services.

Outcomes

Outcomes to date

Project impact on regional group members

To assess the project's impact on knowledge and behaviour of members of the regional groups (described above) surveys were conducted at the beginning of the project (to determine the baseline), at the project mid point, and at the end of the completion of the project. Results of the regional surveys have shown that:

- Farmers in the groups are generally applying less N to both plant and ratoon crops with their cane yields remain largely unchanged,
- More farmers are using past crop yields as a method for determining N rate,
- Farmers are more accurately estimating the amount of N exported to the mill in harvested cane and the amount of N lost to the environment,
- Farmers have refined down how much N they believe is required to grow a tonne of cane and they are more accurately estimating N contributions from legumes and mill mud.

While the majority of farmers have changed N fertiliser practices since the inception of the project, most still want to change further, citing economic and environmental factors as drivers for wanting to change. All of the farmers who have been involved in the project believe this project has helped improve their N management and cite improvements in economics, understanding of environmental impacts, information on baseline crop N needs and an increased awareness of N management as the main benefits.

Miscellaneous outcomes

There have been a range of outcomes in the project to date. In summary these are:

- N Replacement has been adopted as environmentally-beneficial management practice for sugarcane in the Water Quality Improvement Plans for the Douglas Shire, Tully-Murray catchment and the Burdekin Catchment.
- Industry N recommendations moving away from being driven from regional yields towards yield relevant to individual blocks (Attachment 4)
- There is now a stronger and more quantitative basis for defining the amount of N supplied to sugarcane crops by legumes and mill mud. This includes concepts of how to incorporate these supplies into N fertiliser recommendation systems.
- The N Replacement has been adopted or is being tested by farmers and BSES Ltd.
- Further development of the N Replacement system for delivering water quality benefits in the wet tropics has been funded under Reef Rescue.
- The use of NIR for assessing sugarcane nutrition for nutrients other than N is being developed in the SRDC project CSR038.

Outcomes expected

In the future we envisage that the project has the potential to realise the environmental, social and economic benefits described above.

Future Research Needs

N contribution from organic sources

This project has found that N from organic sources is likely to be much higher than previously anticipated. This means that organic sources of N could replace a substantial amount of N applied as fertiliser, and increase farm profitably, if organic N is accounted for fully in N management systems. Conversely, it means that N losses to the environment will be higher than currently thought if organic N is not fully accounted for in N management systems. Given the importance of these ramifications, the results from this project need to be confirmed more widely and more complete work undertaken on managing N from organic sources.

Developing important concepts in the N replacement system

Two assumptions in the N replacement system are (1) that soil N reserves are plentiful, and (2) the additional N applied to allow for unavoidable environmental losses are constant across locations. Our results to date suggest that, for the replacement 'factors' used, these assumptions are valid. However, fear that soil reserves are not plentiful may limit the adoption of the N replacement system. Also, it is unlikely that environmental losses are constant – water logged clay soils may lose much more N through denitrification or a coarse soil in the wet tropics may have much more N leached from the profile. Better understanding of these losses would allow refinement of the replacement 'factor'; potentially reducing the factor in some situations and increasing it in others.

Precision agriculture

Yield monitoring is becoming more widespread in the industry and so there will be a greater awareness of how yield varies across cane blocks. To make full use of these data, management actions responses need to be developed that are 'driven' by yield. These do not currently exist within the industry. However, as yield is the primary driving factor in the N replacement systems it is a 'neat fit' with yield monitoring and precision agriculture, providing a system for applying N at variable rates in response to spatial differences in yield. Further, Bramley et al. (2008, Attachment 5) show how application of N Replacement in this context could reduce N rates below the 1.0 kg t^{-1} tested in this project. Thus there are both financial and environmental gains to be made through developing, testing and applying these concepts in precision agriculture context.

Environmental benefits of N Replacement

The N balances in our experiments suggest that environmental losses of N are substantially reduced under N Replacement. This conclusion needs to be experimentally verified to allow the industry to better estimate the environmental benefits of improved N fertiliser management. Such work would also test our hypothesis that the N surplus (i.e. fertiliser N minus N removed at harvest) is a reliable indicator of (total) N lost to the environment. Determining N surpluses is much cheaper that directly measuring environmental losses of N. So, once proven, the hypothesis would allow environmental impacts of different management practices to be much more widely determined than they traditionally have been.

Sugarcane physiology

Concentrations of N in cane harvested from all treatments at most sites were lower than expected from results of previous field research. Such low N concentrations could be a significant driver for lowering N needs of sugarcane. The reasons for these low concentrations need to be determined. Once known, they could possibly be introduced into breeding programs so that future varieties require even less N.

There was a trend for yields in the NR treatments to exceed those at higher N rates after a few crops. Thus some feature of the N replacement system – imposing periodic mild N stress on cane? – could be triggering a positive physiological response in the crop. More conclusive confirmation of this response and, if proven, the causes of it need to be determined.

Recommendations

We recommend that SRDC consider the research needs identified in this report.

Awards and Invitations

Two papers from the project have won awards for the best agricultural at international conferences paper:

- James E Truine Award, International Society of Sugar Technologists 26th Congress, 2007 (publication # 10).
- Kynoch Award, the South African Sugar Technology Association annual conference, 2004 (publication # 12).

The project team has been invited to present results from the project to a wide range of audiences, including;

- Cardwell Shire Floodplain Program Steering Committee (various)
- Officers of the Federal Government's Departments of the Environment, Water, Heritage and the Arts and Department of Agriculture, Fisheries and Forestry's (November 2007).
- Great Barrier Reef Plan-Reef Partnership (November 2007).
- Australian Cane Farmers Association (AGM Mackay May 2009)
- Australian Fertiliser Industry Federation (annual conference, Coffs Harbour August 2009)

Members of the project team were invited to participate in the development of the Scientific Consensus Committee on Water Quality in the Great Barrier Reef (Brodie et al., 2008a, b)

List of Publications

Papers 1 to 3 are included in this report as Attachments.

Journal papers

1. Park, S.E., Webster, A.J., Horan, H.L., Thorburn, P.J., Biggs, I.M., Biggs, J.S., James, A.T. (2009). Legume rotation crops lessen the need for nitrogen fertiliser throughout the sugarcane cropping cycle, *Crop and Pasture Science*, submitted.

2. Bramley, R.G.V., Hill, P.A., Thorburn, P.J., Kroon, F.J. and Panten, K. (2008). Precision Agriculture for improved environmental outcomes: Some Australian perspectives. *Landbauforschung - vTi Agriculture and Forestry Research* 3(58):161-178.

Referred conference papers

3. Thorburn P.J., Webster A.J., Biggs J.S. and Biggs I.M. (2009). Nitrogen needs of sugarcane crops: Lessons from testing the N Replacement concept. *Proceedings Australian Society Sugar Cane Technologists*, 31: 104-115.

4. Webster, A.J., Thorburn, P.J., Biggs, J.S., Biggs, I.M., Spillman, M.F. and Park, S.E. (2008). N replacement: A simple approach to improving nitrogen use efficiency in sugarcane. *Proceedings Australian Society Sugar Cane Technologists*, 30: 355-356.

5. Thorburn, P.J., Webster, A.J. and Biggs, J.S (2008). Nitrogen balances in sugarcane farming systems as affected by Nitrogen fertiliser applications. *Proceedings Australian Society Sugar Cane Technologists*, 30: 357-358.

6. Park, S., Horan, H., Webster T., Biggs, I., Biggs, J. and Thorburn, P. (2008). Adapting sugarcane nitrogen management practices to take account of legume fallows. *Proceedings Australian Society Sugar Cane Technologists*, 30: 365-366.

7. Thorburn P.J., Park S.E., Bloesch P., Webster A.J., Horan H.L., Biggs I.M. and Biggs J.S. (2008). Potential impacts of mill mud on nitrogen fertiliser requirements for sugarcane production. *Proceedings Australian Society Sugar Cane Technologists*, 30: 367-368.

8. Biggs, I.M., Webster, A.J., Thorburn, P.J., Staunton, S. and Biggs, J.S. (2008). Monitoring N stress in sugarcane: Approaches at the mill using total N. *Proceedings Australian Society Sugar Cane Technologists*, 30: 372-373.

9. Thorburn, P.J., Webster, A.J., Biggs, I.M., Biggs, J.S., Park, S.E. and Spillman, M.F. (2007). Innovative management of nitrogen fertiliser for a sustainable sugar industry. *Proceedings Australian Society Sugar Cane Technologists*, 29: 85-96.

10. Thorburn, P.J., Webster, A.J., Biggs, I.M., Biggs, J.S., Staunton, S.P. and Park, S.E. (2007). Systems to balance production and environmental goals of nitrogen fertiliser management. In: Hogarth, D.M. (ed.)

International Society Sugar Cane Technologists Proceedings XXVI^th Congress, Durban July 2007, South African Society Sugar Cane Technologists Association and XXVI^th ISSCT Organising Committee, pp 302-311 (on CD).

11. Thorburn P.J., Webster A.J., Biggs I.M., Biggs J.S. and Park S.E. (2007). A simple balance approach to improving nitrogen use efficiency in sugarcane. In: Bosch A.D., Teira, M.R. and Villar J.M. (Eds), *Towards a better efficiency in N use*, Universitat de Leida, Leida Spain and Editoral Milenio, pp 152-154.

12. Thorburn, P.J., Horan H.L., Biggs, I.M. and Park, S.E. (2004). Which is the most important crop when assessing nitrogen applications – the next or the last? *Proceedings of the South African Sugar Technologists' Association*, 78: 383-391.

Conference abstracts

13. Thorburn P.J., Webster A.J., Biggs I.M., Biggs J.S. and Park S.E. (2007). A simple balance approach to improving nitrogen use efficiency in sugarcane. In: Bosch-Sera A.D., Esmatges, M.R.T. and Villar J.M. (Eds), Towards a better efficiency in N use: book of abstracts (Ministry of Agriculture, Lleida, Spain), p 81.

14. Thorburn P.J., Webster A.J., Biggs I.M., Biggs J.S., Park S.E. and Spillman M.F. (2006). Innovative management of nitrogen fertiliser: Testing the N Replacement concept. *Proceedings Australian Society Sugar Cane Technologists*, 28: 599.

15. Thorburn P.J., Webster A.J., Biggs J.S., Biggs I.M., Park S.E. and Spillman M.F. (2006). Innovative management of nitrogen fertiliser for sugarcane production. In: ASSSI-ASPAC-ACMS National Soils Conference Soil Science Solving Problems: Book of Abstracts, p 40.

Other publications

16. Brodie, J., Binney, J., Fabricius, K., Gordon, I., Hoegh-Guldberg, O., Hunter, H., O'Reagain, P., Pearson, R., Quirk, M., Thorburn, P., Waterhouse, J., Webster, I. and Wilkinson, S. (2008) Synthesis of evidence to support the Scientific Consensus Statement on Water Quality in the Great Barrier Reef. The State of Queensland (Department of the Premier and Cabinet), Reef Water Quality Protection Plan Secretariat, Brisbane, 84 pp.

17. Brodie, J., Binney, J., Fabricius, K., Gordon, I., Hoegh-Guldberg, O., Hunter, H., O'Reagain, P., Pearson, R., Quirk, M., Thorburn, P., Waterhouse, J., Webster, I. and Wilkinson, S. (2008) Scientific Consensus Statement on Water Quality in the Great Barrier Reef. The State of Queensland (Department of the Premier and Cabinet), Reef Water Quality Protection Plan Secretariat, Brisbane, 6 pp.

References

Barry, G.A., Price, A.M. and Lynch, P.J. (1998). Some implications of the recycling of sugar industry by-products. *Proc. Aust. Soc. Sugar Cane Technol.*, **20**, 52-55.

Barry, G.A., Rayment, G.E., Jeffrey, A.J. and Price, A.M. (2001). Changes in cane soil properties from applications of sugarmill by-products. *Proc. Aust. Soc. Sugar Cane Technol.*, **23**, 185-191.

Bramley, R.G.V., Hill, P.A., Thorburn, P.J., Kroon, F.J. and Panten, K. (2008). Precision Agriculture for improved environmental outcomes: Some Australian perspectives. *Landbauforschung - vTi Agriculture and Forestry Research.*, 3, 161-178.

Brodie, J., Binney, J., Fabricius, K., Gordon, I., Hoegh-Guldberg, O., Hunter, H., O'Reagain, P., Pearson, R., Quirk, M., Thorburn, P., Waterhouse, J., Webster, I. and Wilkinson, S. (2008a). Synthesis of evidence to support the Scientific Consensus Statement on Water Quality in the Great Barrier Reef. The State of Queensland (Department of the Premier and Cabinet), Reef Water Quality Protection Plan Secretariat, Brisbane, 84 pp.

Brodie, J., Binney, J., Fabricius, K., Gordon, I., Hoegh-Guldberg, O., Hunter, H., O'Reagain, P., Pearson, R., Quirk, M., Thorburn, P., Waterhouse, J., Webster, I. and Wilkinson, S. (2008b). Scientific Consensus Statement on Water Quality in the Great Barrier Reef. The State of Queensland (Department of the Premier and Cabinet), Reef Water Quality Protection Plan Secretariat, Brisbane, 6 pp.

Calcino, D.V. (1994). Chemical inputs into the Australian sugar industry. BSES Extension Workshop: Offsite movement of agrochemicals in tropical sugarcane production.

Carberry, P.S., McCown, R.L., Muchow, R.C., Dimes, J.P., Probert, M.E. and Dalgliesh, N.P. (1996). Simulation of a legume ley farming system in northern Australia using the Agricultural Production Systems Simulator. Aust. *J. Exp. Agric.*, **36**, 1037-1048.

Chapman, L.S. (1994). Fertiliser N management in Australia. *Proc. Aust. Soc. Sugar Cane Technol.,* **16**, 83-92.

Eickhout, B., Bouwmana, A.F. and van Zeijts, H. (2006). The role of nitrogen in world food production and environmental sustainability. *Agr. Ecosyst. Environ.,* **116**, 4-14.

Garside, A.L., Berthelsen, J.E., Richards, C.L. and Toovey, L.M. (1996). Fallow legumes on the wet tropical coast: some species and management options. *Proc. Aust. Soc. Sugar Cane Technol.* **18**, 202-208.

Keating, B.A., Verburg, K., Huth, N.I. and Robertson, M.J. (1997). Nitrogen management in intensive agriculture: sugarcane in Australia. In 'Intensive sugarcane production: Meeting the challenges beyond 2000'. (Eds BA Keating, JR Wilson) pp. 221-242. (CAB International: Wallingford).

Keating, B.A., Kingston, G., Wood, A.W., Berding, N. and Muchow, R.C. (1999). Monitoring nitrogen at the mill to guide N fertilisation practice on farm. *Proc. Aust. Soc. Sugar Cane Technol.* **21**, 10-19.

Keating, B.A., Webster, A.J. and Biggs, I.M. (2003). Improving CCS in the wet tropics via block-specific monitoring of N in cane delivered to the mill: Final report. CSIRO Sustainable Ecosystems, St. Lucia, Qld. http://www.srdc.gov.au/ProjectReports/ViewReports.aspx?ProjectNo=CTA045.

Meyer, J.H. and Wood, R.A. (1994). Nitrogen management of sugar cane in South Africa. *Proc. Aust. Soc. Sugar Cane Technol.* **15**, 93-104

Muchow, R.C., Robertson, M.J., Wood, A.W. and Keating, B.A. (1996). Effect of nitrogen on the time-course of sucrose accumulation in sugarcane. *Field Crop Res.*, **47**, 143-153.

Neeteson, J.J. (1995). Nitrogen management for intensively grown arable crops and field vegetables. In 'Nitrogen fertilisation and the environment'. (Ed. PE Bacon) pp. 295-325. (Marcel Dekker: New York).

Probert, M.E., Dimes, J.P., Keating, B.A., Dalal, R.C. and Strong, W.M. (1998). APSIM's water and nitrogen modules and simulation of the dynamics of water and nitrogen in fallow systems. *Agr. Sys.,* **56**, 1-28.

Schroeder B.L. and Barnard R.O. (2002). A remedy for dealing with moisture stress conditions during sugarcane leaf sampling. *Proc. South African Sugar Technol. Assoc.,* **74**, 87-92.

Schroeder, B.L., Wood, A.W. and Kingston, G. (1998). Re-evaluation of the basis for fertiliser recommendations in the Australian sugar industry. *Proc. Aust. Soc. Sugar Cane Technol.* **20**, 239-247.

Schroeder, B.L., Wood, A.W. and Kingston, G. (2002). An integrated approach to nutrient management in the Australian Sugar Industry. *Proc. South African Sugar Technol. Assoc.,* **76**, 79-82.

Schroeder, B., Panitz, J., Wood, A., Moody, P. and Salter, B. (2007). *Soil-specific nutrient management guidelines for sugarcane production in the Bundaberg district*. BSES Limited Technical Publication TE07004. pp 76.

Schroeder, B., Panitz, J., Wood, A., Moody, P. and Salter, B. (2008). *Accepting the adoption of best-practice nutrient management: Wet Tropics.* BSES Technical Report. Brisbane.

Schroeder B.L., Wood, A.W., Kingston, G., Meyer J. and Barnard R.O. (1999). Leaf analysis–What does it offer the Australian sugar industry? *Proc. Aust. Soc. Sugar Cane Technol.* **21**, 122-130.

Staunton, S.P., Lethbridge, P.J., Grimley, S.C., Streamer, R.W., Rogers, J. and Mackintosh, D.L. (1999). On-line cane analysis by near infra-red spectroscopy. *Proc. Aust. Soc. Sugar Cane Technol.* **21**, 20-27

Stewart, L.K., Charlesworth, P.B., Bristow, K.L. and Thorburn, P.J. (2006). Estimating deep drainage and nitrate leaching from the root zone under sugarcane using APSIM-SWIM. *Agr. Water Manage.,* **81**, 315-334.

Thorburn, P.J., Park, S.E. and Biggs, I.M. (2003a). Nitrogen fertiliser management in the Australian sugar industry: strategic opportunities for improved efficiency. *Proc. Aust. Soc. Sugar Cane Technol.* **25**, (on CD-ROM) 12pp.

Thorburn, P.J., Dart, I.K., Biggs, I.M., Baillie, C.P., Smith, M.A. and Keating, B.A. (2003b). The fate of nitrogen applied to sugarcane by trickle irrigation. In 'Micro-irrigation: Advances in system design and management'. (Eds PJ Thorburn, KL Bristow, J Annandale). *Irrigation Sci.* **22**, 201-209.

Thorburn, P.J., Meier, E.A. and Probert, M.E. (2005). Modelling nitrogen dynamics in sugarcane systems: Recent advances and applications. *Field Crop Res.,* **92**, 337-352.

Wood, A.W., Muchow, R.C. and Robertson, M. (1996). Growth of sugarcane under high input conditions in tropical Australia. III. Accumulation partitioning and use of nitrogen. *Field Crop Res.,* **48**, 223-233.

Wood, A.W., Bramley, R.G.V., Meyer, J.H. and Johnson, A.K.L. (1997). Opportunities for improving nutrient management in the Australian sugar industry. In 'Intensive sugarcane production: Meeting the challenges beyond 2000'. (Eds BA Keating, JR Wilson) pp. 253-266. (CAB International: Wallingford).
Wood, A.W., Schroeder, B.L. and Stewart, R.L. (2003). The development of site-specific nutrient management guidelines for sustainable sugarcane production. *Proc. Aust. Soc. Sugar Cane Technol.* **25**, (on CD-ROM) 8 pp.

Nitrogen Workshop #3

Tuesday 27th and Wednesday 28th May 2008

Townsville

Scenarios for Nitrogen Application in the Australian Sugar Industry

Workshop report

Introduction

Rising nitrogen (N) fertiliser costs, continuing public concern about the welfare of the Great Barrier Reef and the looming need to reduce greenhouse 'footprints' have created an environment where excessive use of N fertiliser in sugarcane production systems is more undesirable than ever. However, these concerns raise the question: What is **excessive** use of N fertiliser?

In 2004, SRDC funded two new projects exploring improved N management. One (BSS268) focussed on accelerated adoption of best-practice nutrient management, which included soil-specific approach to managing N embodied in the SIX EASY STEPS program[A]. The other (CSE011) sought to field test a new system, the N Replacement system[B], for determining N fertiliser rates based on yields of previous crops using new information on the amount of N contained in sugarcane crops. Within both projects was a commitment discus the relative merit of the different approaches, overlaps within them and identify future steps in N fertiliser management for the Australian sugarcane industry. Industry workshops were held each year to facilitate those discussions, and ensure involvement of a wide range of stakeholders. In 2008, the third and final workshop in that series was held.

The aim of this workshop was to review:

1. Progress made in the field testing of the N Replacement system,
2. Insights gained and lessons learnt in the SIX EASY STEPS adoption process, to
3. Recommend actions so the information gained in these projects could best help growers and the industry with their N fertiliser management practices.

This report summarises the workshop and list the discussion and decisions made at there.

Workshop structure

The workshop was structured around examination of two hypothetical scenarios about deciding how much N fertiliser to apply to a block of sugarcane. The scenarios were considered by small groups, with the decisions reached and the factors influencing those decisions presented to and discussed amongst the whole workshop. The scenarios were prefaced by presentations on Aims 1 and 2, above. The issues raised in these discussions were used to formulate actions to build on the knowledge gained do date. The workshop program is given in the Appendix.

Twenty eight people (listed in the Appendix) were invited to the workshop representing the teams from both projects and a range of industry stakeholders. The workshop was facilitated by Mary Maher of Mary Maher and Associates.

How important is nitrogen fertiliser management?

To gauge the perspective of workshop participants (excluding members of the respective project teams) on the importance of topic of the workshop, participants were asked to respond to two questions on the importance of N fertiliser management. Responses on a scale of 1 to 5 are shown in Table 1.

AS well as recording the individual scores, comments on why individuals gave a particular score were as recorded. The main comments for Q1 centred on nitrogen's critical role for cane production, and role of fertiliser costs and Reef issues in requiring the production gaol was achieved without waste. For the second question, comments included:

[A] Schroeder et al. (2006). Proc ASSCT 28:142
[B] Thorburn et al. (2003). Proc ASSCT 25.

- Growers currently ‘muddle through’ the decision.
- Growers need as much information as possible to get the right rates.
- Costs mean it is more important then ever to use the least amount of N to maintain production.
- Greater confidence (in N management) frees up time to concentrate on other issues on the farm.

Participants said that the lower mean score for the first question was influenced by the fact that: (1) N management isn’t the only priority on the farm, and/or (2) you can grow ‘good cane’ with high application rates (i.e. the decision can be simple if you are prepared to use high rates). It is when growers are trying to balance minimising N applications with maximising productivity that N management becomes complex.

Table 1. Responses to two questions on the importance of N fertiliser management.

Question	Score									Mean
1. How important is N management in sugarcane growing?	4	5	2-5	4	4	5	4	5	3	**4.2**
2. How important is the system used to decide the N rate?	5	4	5	5	4	5	5	5	5	**4.8**

Scenarios

Participants were split into three small groups, ensuring an even spread of skills/knowledge between the groups, for considering the scenarios. Following distribution of Scenario 1 (Box 1), there was a presentation on interpreting the scenario through the ‘lens’ of each N management system; SIX EASY STEPS (6ES) and N Replacement. The groups then considered the scenario and determined the N rate they would apply and the reasons for the decision. For Scenario 2 (Box 1), the groups were reorganised and the same process was then followed.

Contrasting N rates would be recommended for each of these scenarios by the two N management systems, with lower rates from N Replacement than the 6ES (Table 2). In most cases the groups agreed upon a range of rates accounting for the different views of group members and uncertainty associated with the necessarily brief description of the scenario. The agreed range was within that recommended from the two systems, i.e. higher than N Replacement but lower than 6ES.

Table 2. N rates determined for each scenario from the two N management systems and by the three groups.

Scenario	N Replacement	SIX EASY STEPS	Group 1	Group 2	Group 3
1. Bundaberg	85 kg/ha	150 kg/ha	100-140 kg/ha	85-109 kg/ha	85-130 kg/ha
2. Tully	100 kg/ha	140 kg/ha	110-120 kg/ha	100 kg/ha, with an option to apply a further 40 kg/ha if needed	115-140 kg/ha

Box 1. N Management scenarios discussed at the workshop.

Exercise – how much N will you apply to this crop?

The year is 2020 and you are about to decide on the amount of N fertiliser to apply to one of the blocks of cane on your farm.

There are two scenarios: an irrigated farm in Bundaberg and a farm in Tully. In 2020 the price of sugar is $350 per tonne and the cost of urea is $1,100 per tonne.

Please decide how much N w you will apply and the factors that are used in making your decision.

1. Fertilising an irrigated 3rd ratoon crop at Bundaberg

- Red sandy loan at Bundaberg (Soil C = 0.8 %)
- Block has been GCTB for > 10 years
- 2nd ratoon crop, harvested in late August 2020 (12 months old), yielded 85 tch
- Previous crop yielded 120 (P) and 90 (1R) tch
- N applied to previous crops was 105 (P) and 140 (both 1R and 2R) kg N/ha
- Variety – Q138
- Rainfall for the 2R crop was 900 mm
- Irrigation allocation for the three previous crops was 4 ML/ha
- Irrigation water is now limited to 1.5 ML / ha (reduced allocation)
- Other nutrients – soil test OK for other nutrients and they were applied at recommended rates
- Mill average yield for that year was 80 tch

2. Fertilising a 1st ratoon crop at Tully

- Grey sandy clay loam at Tully (Soil C = 1.1 %)
- Long term GCTB
- The crop was planted in June 2019, harvested in mid October 2020 and yielded 100 tch
- N was applied to plant crop 70 kg N/ha
- Rainfall for the plant crop was 4000 mm
- Block fronts on to a creek and down steam the is a water quality monitoring station
- A cowpea crop was grown in the fallow and ploughed in
- Variety – Q117
- Other nutrients – soil test OK for other nutrients and they were applied at recommended rates
- Mill average yield for that year was 90 tch

Comments on the reasons for the decisions included the following:

1. Bundaberg
    - N Replacement idea gives ‘comfort’ to go as low as 85 kg/ha.
    - Missing detailed history of block – important information for farmers’ confidence and making an exact decision.
    - Weighing up the gains of savings through reduced N *v.* the possible loss of production. The latter is harder to know.

- Late ratoon, limited irrigation water, so unlikely to have a high yield. Hence apply low N (85 kg/ha).
- It would be good to know how much N is in the soil.
- Depends on individual's attitude to risk.

2. Tully
   - Assumed soil N reserves low (because of climate).
   - Unlikely carry over from previous crop.
   - How big will the crop be – 70 TCH or 100 TCH?
   - It's a 'hungry variety', need to feed it N.
   - Good to have options to have split N applications, slow release fertiliser, etc.
   - Plant crop was not a robust plant crop, so might not be a good ratoon crop.

The assumption of low soil reserves N the wet tropics is interesting given that a number of studies have found substantial amounts of soil mineral N in cane blocks in that region[C].

In working through the scenarios, it also became evident that a number of participants were using a flexible approach to the yield goal in 6ES. Within 6ES there is constant yield goal for each region[D]. When applying 6ES in the scenarios some participants used a different yield goal, one they felt was more relevant to the block. This is reflected in the comments "*late ratoon, limited irrigation water, so unlikely to have a high yield*" and "*plant crop not a robust plant crop, so might not be a good ratoon crop*".

Overview of issues

During the workshop a number of general issues arose. These were captured and summarised below.

1. Participants summarised that the two key differences between the systems, and hence the two key questions to be answered when deciding how much N to apply, were;

   a. What is the expected yield of the crop, and
   b. How much N is required to grow a tonne of sugarcane?

   In the 6ES program the yield expectation is a regional potential yield whereas the N Replacement system uses the yield of the previous crop. The answer to question (b) is slightly more complex, but can be approximated as 1.4 kg N/t cane, with some variation for soil type, in 6ES, and 1 kg N/t cane for N Replacement in the majority of Australian sugarcane production. The N Replacement also recommends different management for green and burnt systems, whereas the 6ES systems does not distinguish between the two.

2. There was recognition that there are many other factors, not considered in 6ES or the N Replacement systems that need to be considered (e.g., variety, block history, grower's attitude to risk, grower's financial position, etc.). Recommendations of N rates need to be made within the context that they are one factor that will be used by growers when making decisions.

3. Participants saw that there various way to determine N rate, e.g. the systems discussed, the fixed rates of Calcino (1994), etc. It is important for grower's (and their advisors) know what the options for N management are. Following from the previous point, participants felt that all these

[C] Hurney et al. (2003) BSS180 SRDC Final Report. Thorburn and Goodson (2005) Proc ASSCT 27:158. Meier et at. (2006) Nutr. Cycling Agroecosys 75:101.
[D] Schroeder et al. (2006). Proc ASSCT 28:142.

systems should be made available to growers in the form of a flexible decision support system or guidelines so that individuals can decide which is appropriate for their circumstances. For example, 'early adopters' should be able to choose a different scheme from the majority of growers.

4. There are still a number of key knowledge gaps:

    a. What evidence do we have that changing N application rates will change environmental losses? While improving environmental outcomes of sugarcane growing is promoted as a benefit of adopting different recommendations of (lower) N rates, there is little empirical evidence to support these claims.
    b. A key knowledge gap is supply of N from soil. 6ES uses predictions of soil mineralising capacity and N Replacement assumptions of the soil's ability to buffer N supply (through mineralisation and immobilisation).
    c. The N needs of different varieties needs to be better defined.

5. There was support for testing of the N replacement system to be continued: There was a need to move beyond the plot scale to gain greater confidence in the system.

Way forward

A number of actions were recommended from the workshop:

1. Add a 'two page' description to SIX EASY STEPS manuals describing flexibility that can used in interpreting expected yields – regional averages as in current manuals v. a more realistic yield likely for a specific block, closer to the concepts in the N Replacement system – and different amounts of N required per tonne of cane.

2. Develop a flexible framework to facilitate individual growers choosing their expected yield and the amount of N needed (per tonne of cane) to achieve that.

3. Initiate research to address the knowledge gaps identified above, especially demonstration of the relationship between reduced N fertiliser applications and reduced environmental losses of N.

4. Look for links to precision agriculture as a technology to facilitate improved N management.

5. Look for a diverse range of sources to fund these activities.

Appendix. Details of the workshop program and invitees.

Table A-1. Workshop program.

Scenarios for Nitrogen Application in the Australian Sugar Industry – Workshop #3

Midday 27 to 1.00pm 28 May 2008, Townsville
Facilitator: Mary Maher

Tues 27th Time			**Topic**	**Speaker/s**
12:15	**-**	**1:00**	**LUNCH**	
1:00	-	1:25	Introduction and session outline, outputs	Mary Maher
1:25	-	1.35	Investing in continuous improvement	Les Robertson
1.35	-	2:00	Six Easy Steps Adoption Process – insights into adoption, lessons learnt	Bernard Schroeder et al.
2:00	-	3:00	Update on N replacement project results Q & A	Peter Thorburn
3:00	**-**	**3:20**	**AFTERNOON TEA**	
	-		Exercise – how much N will you apply to this crop? The year is 2020 and you are about to decide on the amount of N fertiliser to apply to one of the blocks of cane on your farm. Please decide how much N w you will apply and the factors that are used in making your decision.	Tony Webster, Bernard Schroeder
3:20		3:40	Scenario(s) introduced; application logic checklist introduced	
3:40	-	4.30	Scenario 1. Group design of the application	Mary Maher
4.30	-	5:30	Scenario 1. Group discussion of key insights	Mary Maher

Wed 28th Time			**Topic**	**Facilitation**
8.45		9.00	Tea and coffee on arrival	
9.00	-	9:10	Session overview	Mary Maher
9:10	-	10:30	Scenario 2. Group design of the application & insights identified	Mary Maher
10:30	**-**	**11:00**	**MORNING TEA**	
11:00	-	12:00	Review session: gaps, limitations, unknowns; Environmental, social, economic implications; Pathway for developing, testing, packaging	Mary Maher
12.00		12.30	Closing comments, value of working session	Les Robertson
12:30	**-**	**13:00**	**LUNCH**	