WHICH IS THE MOST IMPORTANT CROP WHEN ASSESSING NITROGEN APPLICATIONS – THE NEXT OR THE LAST?

P J THORBURN, H L HORAN, I M BIGGS and S E PARK

CSIRO Sustainable Ecosystems, Queensland Bioscience Precinct, 306 Carmody Rd, St. Lucia, Qld 4067, Australia. E-mail: Peter.Thorburn@csiro.au

Abstract

A review of nitrogen (N) fertiliser management in the Australian sugar industry was undertaken to identify new strategies to improve N fertiliser use efficiency and to fill gaps in knowledge relevant to N fertiliser management. The Australian sugar industry has a history of high N fertiliser usage, with applications increasing from the 1960s to the late 1990s. However, industry average sugarcane production has not kept pace with N fertiliser applications, resulting in a steady increase in N fertiliser applied per ton of sugarcane harvested. Historical and recently developed N management strategies rely on matching N applications to the predicted/expected yield of the forthcoming crop. High applications of N fertiliser by farmers are a rational reaction to (i) the uncertainty of these predictions/expectations, and (ii) the yield reductions caused by long-term under-fertilising with N. While **sustained** under-application of N undoubtedly reduces cane yields, there is considerable evidence in the Australian industry that greatly reducing N fertiliser applications for a **single** crop does not significantly reduce sugarcane production. Consequently, a new philosophy of N fertiliser management can be envisaged, that removes the uncertainty driving farmers' decisions to over-apply N. Rather than aiming at fertilising the coming crop, one could aim at replacing the amount of N lost from the previous crop, the majority of which is in harvested cane and can be easily estimated. To better examine this new 'replacement' N management strategy, long-term simulations were undertaken of sugarcane production in four regions in Australia and one in South Africa. The replacement strategy had similar productivity, greater profitability and lower environmental N losses than conventional N fertiliser management. The choice of soils and the inclusion of a South African climate in the simulations ensured that the results are biophysically relevant to the South African industry. However, before this system can be considered as a practical N fertiliser management system in any country, it needs extensive field testing. A testing programme is commencing in Australia.

Keywords: sugarcane, denitrification, fertiliser response, nitrate, leaching, nitrogen mineralisation, soil organic matter, systems modelling

Introduction

In common with other intensive agricultural production systems, the Australian sugar industry has a history of high N fertiliser usage. Average N fertiliser applications across the whole industry increased from around 100 kg/ha in the 1960s to around 200 kg/ha in the late 1990s (Thorburn *et al.*, 2003b). This is a result of the promotion of N fertiliser usage, and the development of industry N fertiliser use recommendations (as described by Schroeder *et al.*, 1998).

However, sugarcane production has not kept pace with N fertiliser applications. In the 1960s there was an average of 1.5 kg N fertiliser applied per ton of sugarcane harvested, increasing to ~2.5 kg N/t cane around 2000 (Figure 1). Excess N fertiliser applications can have deleterious consequences for profitability, sucrose concentrations, sugar quality and environmental impacts in sugarcane growing areas. Some of these issues are currently of particular concern in Australia. The low prices Australian farmers received for sugar in recent times means that matching farm inputs to sugarcane production is especially important, to underpin the financial viability of sugar farms. Also, there is evidence of elevated concentrations of N in subsoils (Keating *et al.*, 1996; Rasiah and Armour, 2001), groundwaters (Thorburn *et al.*, 2003a) and surface waters (Bramley and Roth, 2002) of sugarcane growing areas which is fuelling public concern about the health of the Great Barrier Reef (Anon., 2001). There is thus the need to develop a N fertiliser management system that promotes better matching of N applications to requirements of sugarcane crops.

This paper briefly examines the factors influencing the N management strategies of Australian sugarcane farmers. A new approach to management of N fertiliser in Australian sugarcane systems is suggested, and this approach is examined using cropping systems simulation. Whether this approach has relevance to the South African sugar industry is also considered.

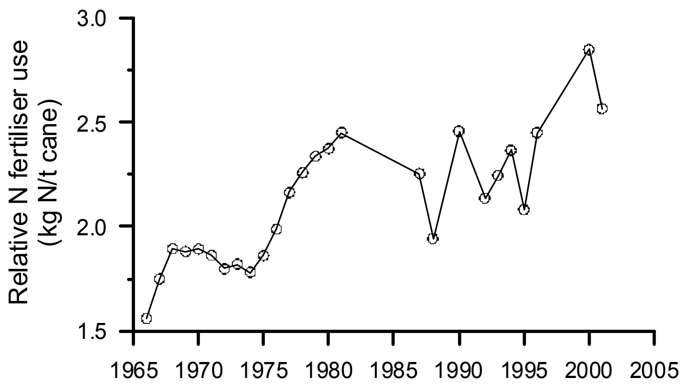

Figure 1. N fertiliser applications relative to sugarcane production for the Australian sugar industry (after Thorburn *et al.,* 2003b).

Factors influencing farmers' decisions about N fertiliser management

Australian sugarcane farmers (and advisors) use published recommendations as only one source of information. Other factors include soil types, varieties, farm management variables (e.g. irrigation, trash retention, availability of equipment), crop cycle length, weather, sugar prices and fertiliser costs (Johnson, 1995). It is also likely that information for a specific farm or block is more likely to influence farmers' decisions than more general information (Johnson, 1995; Keating *et al.,* 1997; Wood *et al.*, 1997; Schroeder *et al.*, 1998).

Keating *et al*. (1997) and Brennan *et al*. (1999) also argue that risk and uncertainty are major factors influencing farmers' decisions about N fertiliser management. Farmers' profitability is influenced more by productivity than by the cost of N fertiliser; thus, gross margins are higher with above-optimal N inputs than below-optimal inputs (Figure 2). It is impossible to accurately forecast the yield of the forthcoming crop in most parts of the Australian industry, due to uncertainties about rainfall, cyclones and the availability of irrigation water. It is therefore a rational **short-term** tactic to minimise risk of low production/profits by applying high rates of N fertiliser, driven by the uncertainty about the size of the forthcoming crop.

Implicit in farmers' reasoning is the assumption that long-term average N response curves (such as the example in Figure 2) apply to each **individual** year, i.e. applying little or no N fertiliser in any specific year will dramatically reduce yields. However, there is considerable evidence to the contrary; that applying <50 kg N/ha for one year reduces yields by <10% (Chapman, 1994; Vallis *et al.*, 1994; Muchow *et al.,* 1996) and applying no N for two years reduces yields by <25% (Thorburn *et al.,* 2003c). The small impact of withholding N fertiliser for a crop or two may have arisen for a number of reasons, e.g. because there were large quantities of mineral N in the profile at the beginning of the experiment, or the mineralising capacity of the soil was sufficient to supply much of the crop's needs during the experiment. Whatever the reasons, these experiments show that the risk of yield reductions from applying, say, 80 kg N/ha to crop instead of 160 kg N/ha (the recommended rate) is much lower than generally considered. Rather than Australian sugarcane farmers considering the 'N tank' in the soil to be empty at the beginning of a crop, they could consider it nearly full.

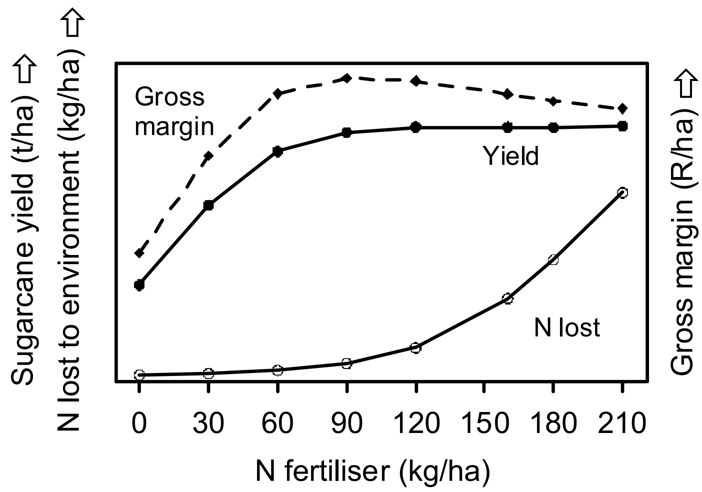

Figure 2. Hypothetical, long-term response of sugarcane yield, environmental losses of N and farm gross margin to increasing applications of N fertiliser.

While farmers may be concentrating on the risks of yield reductions, there are other longer-term risks associated with sugarcane production that also have the potential to substantially limit production and hence farm business profitability (Brennen *et al.,* 1999). One is the risk of soil and water degradation, as described above. Another is institutional risk – that is, the risk that society (through government) may regulate N management practice to reduce or prevent soil and water degradation. While self-regulation is the most common path taken in Australia, the recent draft water quality targets for rivers draining into the Great Barrier Reef lagoon (Anon., 2001) show that the 'threat' of government regulation is real.

To minimise risks associated with soil and water degradation, N fertiliser applications need to be closely matched to the crop's requirements (Wood *et al.,* 1997; Keating *et al.*, 1997). To minimise institutional risks, N fertiliser management must be evidence-based, transparent and defensible.

Advances in nitrogen fertiliser management recommendations

In recent times, N fertiliser management strategies have been further developed, allowing for N inputs from mineralisation of organic matter in different soils (Wood *et al.*, 2003), following the South African system (Meyer and Wood, 1994). In Australia, this system results in recommendations considerably lower than previous recommendations in all situations except for large crops (>120 t) grown on soil with low organic matter. Schroeder *et al*. (2002) encourages farmers to also undertake soil (Schroeder *et al.*, 1998) and leaf (Schroeder *et al*., 1999) testing programs to monitor the N nutrition status of sugarcane crops. However, the concept of farmers deciding on a target yield is still central to this system, and so it may still result in over-application of N fertiliser in Australian systems for the reasons discussed above. This raises the question – how can the link between N fertiliser recommendations and target yield be broken?

As stated above there is considerable evidence that, in many cases, the N mineralisation capacity of the soil and/or soil mineral N reserves are sufficient that little N fertiliser is required to provide an adequate N supply for a **single** crop. Rather than thinking that the soil 'N tank' is nearly empty, there is good reason to think that in many cases it is more likely to be nearly full.

By making this assumption, the philosophy of N fertiliser management can be changed. N fertiliser need not be thought necessary to ensure the yield of the forthcoming crop, but required to replace the N removed from the site via the previously harvested crop. Thus, **uncertainty** surrounding yield of the forthcoming crop is replaced by the **certainty** of N removed in the previous crop. For each block, the off-take of N can be readily estimated from the measured cane yield in combination with information on N concentrations in cane, gained from either 'rule-of-thumb' or direct measurements made at mills.

Investigating the N replacement system through simulation

To further explore the implications of the 'N replacement' concept of fertilising, long-term simulations were run using the APSIM cropping systems simulator for two different N fertiliser management strategies: (i) N replacement and (ii) current Australian recommended N fertiliser management (Calcino *et al*., 2000). The recommended system had 120 and 160 kg/ha N applied to plant and ratoon crops, respectively. In the replacement system, the amount of N applied to a crop equalled 110% of that in the cane of the previous crop (assuming a cane N concentration of 0.3%). This 'rule' was applied to plant and ratoon crops, assuming they were growing in a green cane harvesting-trash blanketing system, and no account was taken of the impacts of fallows between crop cycles. The 10% application in addition to that lost from the previous crop was made to allow for unavoidable environmental losses of N (not doing this results in severe N deficiency).

Simulations of the two systems were conducted representing green cane harvesting-trash blanketing with a crop cycle consisting of a plant crop and four ratoons, based on the simulation scenarios described by Thorburn *et al.* (2004). Simulations were conducted for a 75 year period. For each strategy simulation outputs focused on potential yields, i.e. yields not limited by pests, diseases, stool damage, lodging, harvesting losses and losses of N to the environment through denitrification and nitrate leaching. Climate and soil parameters were obtained for five regions, four from Australia and one from South Africa, representing a wide range of conditions (Table 1). In each case, the soil data came from an experiment in that area, the results from which had been successfully simulated. Mt. Edgecombe provided a useful comparison to the Australian sites, as the soil had considerably higher clay and organic matter contents than the soil from the Australian sites, and the climate was drier and cooler. Irrigation was applied only in the Bundaberg simulations. There, the total amount of water applied to each crop was capped at 400 mm, representing local restrictions on irrigation water availability.

Table 1. Details of the soils, rainfall and previous simulations undertaken at the five regions used for simulations in this study.

Climate	Soil	Average rainfall (mm/year)	Reference
Bundaberg	red loam/sandy loam	1090 (+ irrigation)	Thorburn *et al.*, 2004
Mackay	brown loam/clay loam	1670	Thorburn *et al.,* 2004
Ingham	light brown silty loam	2200	Thorburn *et al.,* 1999
Tully	brown silty clay	3950	Thorburn *et al.,* 2004
Mt. Edgecombe	grey cracking clay	950	Thorburn *et al.,* 2002

There was little difference in simulated sugarcane yields in either N management system at any site (Figure 3). To provide a more detailed depiction of the yield comparisons, cumulative yields are shown for the Mackay simulations (Figure 4). The yields in the two management systems are very close through the whole period simulated. This similarity shows that there are no periods when one system outperformed the other at Mackay, and the mean simulated yields over all 75 years (shown in Figure 3) are a reasonable representation of shorter time spans (e.g. one crop cycle). Similarly, the 75 year means are also a reasonable representation at the other sites (data not shown).

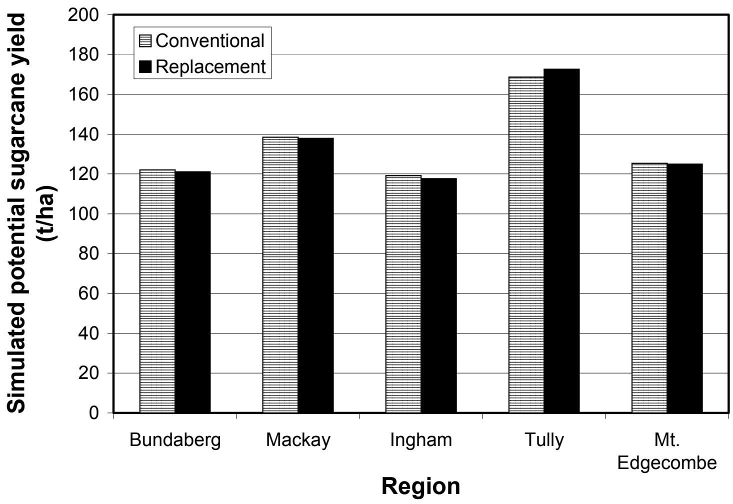

Figure 3. Average potential sugarcane yields simulated over 75 years for conventional N fertiliser management and the N replacement management system at five regions.

N fertiliser applications were lower with the N replacement systems than the conventional system in all regions except Tully. In the conventional N fertiliser management system, an average of 152 kg N/ha was applied to each crop (this being the mean of 120 kg/ha on the plant crop, and 160 kg/ha on the ratoon crops). This N application resulted in yields from 120 to 170 tons cane/ha (Figure 3). When the N application was expressed relative to sugarcane yield, there was 0.9 to 1.3 kg/t cane of N applied in the different regions (Figure 5). This compares with 1.0 kg/t cane of N applied at all sites in the replacement strategy. Where less N was applied through the replacement system (i.e. at all regions except Tully), farm profitability would have been higher (as shown in detail for Mackay by Thorburn *et al.,* 2003b). The lower N applications also resulted in considerably lower N losses to the environment at all sites, as exemplified by the detailed data for Mackay shown in Figure 4. The maintenance of cane productivity with lower N fertiliser inputs did not degrade soil organic matter. There was little difference in simulated soil organic matter amounts in any of the N management systems (data not shown).

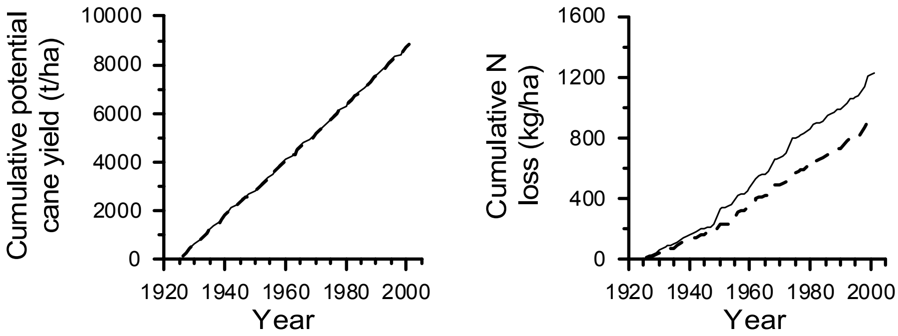

Figure 4. Potential sugarcane yields and environmental losses of N simulated at the Mackay site, cumulated over the 75 years of the simulation, for conventional N fertiliser management (solid lines) and the replacement management system (broken lines).

The results for the Tully region illustrate a characteristic of the simulations undertaken in this study and its impact on the results. The average yield for the Tully region is much higher than that commonly achieved in the region. However, the simulated yield is a potential yield, which is high because of the large rainfall in that district. The N fertiliser applications in the conventional N management system are thus lower than those in the replacement system, but also much lower than those that would be recommended in areas where yields were as high as those simulated for Tully (e.g. the Burdekin region; Calcino *et al.*, 2000). If the actual yields obtained in a region are lower than those simulated, the application of N **relative** to cane yield will increase with the conventional system as illustrated in Figure 5, causing lower farm profitability and higher losses of N to the environment. However, N applications remain at 1.0 kg/t cane in the N replacement system.

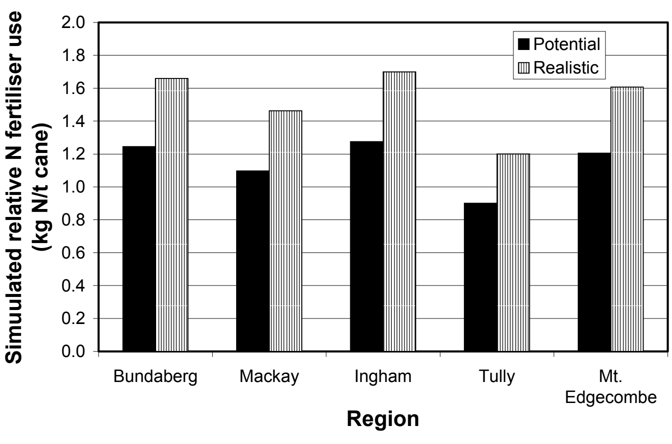

Figure 5. Mean N fertiliser applications relative to sugarcane yields for a conventional N management system simulated over 75 years in five regions, for potential yields and more realistic yield (estimated as 75% of the potential yields).

Discussion

N fertiliser applications are necessary to maintain sugarcane productivity, profitability and soil health. Rates of fertiliser application should be block specific and related to crop yields to minimise losses of N to the environment and the deleterious effects of high N concentrations on crop agronomy and sugar quality. The simulations undertaken in this study illustrate that an N fertiliser management system based on replacing the N exported from farm blocks in previously harvested cane could maintain productivity (Figure 3) and soil quality, improve profitability and decrease N losses to the environment (e.g. Figure 4). A replacement system, like other N fertiliser management systems, would benefit from monitoring crop and soil N status to ensure N deficits or excesses did not occur in the crop, and that soil quality was maintained.

While the simulations suggest that N fertiliser management based on a replacement philosophy has promise, the system needs comprehensive field testing before it can be considered a practical alternative to current ways of managing N. A field testing programme has commenced in Australia and will soon be expanded.

In common with other N fertiliser management systems, the replacement system has uncertainties about how to account for (i) N inputs from sources other than fertilisers, and (ii) N losses from sources/processes other than harvested cane. As regards the first issue, inputs can come from sources such as N fixation in legume crops grown during fallows, N applied to soil through mill by-products or N applied to the soil via fertigation. Fertiliser applications should be discounted for these inputs. In Australia, however, there is considerable uncertainty about the amount of N applied, and the timing of its release from the organic sources mentioned. The South African industry has guidelines to account for N applications from mill by-products (Moberly and Meyer, 1987) and a similar approach could be considered in Australia.

As regards N losses, in simulating an N replacement system an allowance was made for environmental losses. This allowance may need to be district-specific, accounting for areas where N losses from either nitrate leaching or denitrification are high. However, environmental losses of N increase rapidly with increasing applications of N fertiliser (e.g. Figure 2). Conversely, these losses will be minimised under a management system that closely matches N applications to N requirements. The difference between districts may be less than expected, given that the majority of our knowledge of environmental losses of N in Australia has been derived from experiments where N was applied at industry standard rates, but crop growth was generally well below potential production levels (e.g. Prove *et al*., 1997; Rasiah and Armour, 2001). This resulted in an inadvertent over-application of N. Certainly, the assumption of environmental losses being a constant 10% in all regions proved adequate in this study.

Finally, what is the relevance of this study to the South African sugar industry? Biophysically, the study is relevant. Not only was a South African region (Mt. Edgecombe) included, the soils parameterised in some of the other regions are similar enough to South African soils that they have been used in simulations of N dynamics in South Africa (van Antwerpen *et al*., 2002). Socio-economically, the study may be less relevant, depending on the need for better matching N fertiliser applications to actual sugarcane production in South Africa.

Acknowledgements

This study was supported by funds from the Australian sugar industry and the Australian Government through the Sugar Research and Development Corporation, which is gratefully acknowledged. Many colleagues have shared valuable insights with the authors during this review, and they are thanked for their input.

REFERENCES

Anon (2001). Great Barrier Reef catchment water quality action plan. Report to Ministerial Council on targets for pollutant loads, water quality and coastal development. Great Barrier Reef Marine Park Authority, Townsville, Australia.

Bramley RGV and Roth CH (2002). Land use impact on water quality in an intensively managed catchment in the Australian humid tropics. *Mar Freshwater Res* 53(5): 931-940.

Brennan LE, Keating BA, Wegener MK and Kingston G (1999). Economic considerations and managing risk in nutrient management. pp 103-112 In: Bruce RC (Ed). *Sustainable Nutrient Management in Sugarcane Production Short Course.* CRC for Sustainable Sugar Production.

Calcino DV, Kingston G and Haysom M (2000). Nutrition of the plant. pp 153-193 In: Hogarth DM and Allsopp PG (Eds). *Manual of Cane Growing.* Bureau of Sugar Experiment Stations, Indooroopilly, Australia.

Chapman LS (1994). Fertiliser N management in Australia. *Proc Aust Soc Sug Cane Technol* 16: 83-92.

Johnson AKL (1995). Risk perceptions and nutrient management responses in the Australian sugar industry: preliminary results from the Herbert River District. *Proc Aust Soc Sug Cane Technol* 17: 273-275.

Keating BA, Bauld J, Hillier J, Ellis R, Weier KL, Sunners F and Connell D (1996). Leaching of nutrients and pesticides to Queensland groundwaters. pp 151-163 In: Hunter HM, Eyles AG and Rayment GE (Eds). *Downstream Effects of Land Use*. Queensland Department of Natural Resources, Australia.

Keating BA, Verburg K, Huth NI and Robertson MJ (1997). Nitrogen management in intensive agriculture: sugarcane in Australia. pp 221-242 In: Keating BA and Wilson JR (Eds). *Intensive Sugarcane Production: Meeting the Challenges Beyond 2000.* CAB International Wallingford.

Meyer JH and Wood RA (1994). Nitrogen management of sugar cane in South Africa. *Proc Aust Soc Sug Cane Technol* 16: 93-103.

Moberly PK and Meyer JH (1987). Filtercake – a field and glasshouse evaluation. *Proc S Afr Sug Technol Ass* 52: 131-136.

Muchow RC, Robertson MJ, Wood AW and Keating BA (1996). Effect of nitrogen on the time-course of sucrose accumulation in sugarcane. *Field Crop Res* 47: 143-153.

Prove BG, Moody PW and Reghenzani JR (1997). Nutrient balances and transport from agricultural land and rainforest lands: a case study in the Johnstone River catchment. LWRRDC Final Report (SRCI).

Rasiah V and Armour JD (2001). Nitrate accumulation under cropping in the Ferrosols of Far North Queensland wet tropics. *Aust J Soil Res* 39: 329-341.

Schroeder BL, Wood AW and Kingston G (1998). Re-evaluation of the basis for fertiliser recommendations in the Australian sugar industry. *Proc Aust Soc Sug Cane Technol* 20: 239-247.

Schroeder BL, Wood AW and Kingston G (2002). An integrated approach to nutrient management in the Australian sugar industry. *Proc S Afr Sug Technol Ass* 76: 79-82.

Schroeder BL, Wood AW, Kingston G, Meyer JH and Barnard RO (1999). Leaf analysis - What does it offer the Australian sugar industry? *Proc Aust Soc Sug Cane Technol* 21: 122-130.

Thorburn PJ, Biggs JS, Weier KL and Keating BA (2003a). Nitrate in groundwaters of intensive agricultural areas in coastal northeastern Australia. *Agricult Ecosys Environ* 94: 49-58.

Thorburn PJ, Dart IK, Biggs IM, Baillie CP, Smith MA and Keating BA (2003c). The fate of nitrogen applied to sugarcane by trickle irrigation. *Irrig Sci* 22: 201-209.

Thorburn PJ, Horan HL and Biggs JS (2004). The impact of trash management on sugarcane production and nitrogen management: a simulation study. *Proc Aust Soc Sug Cane Technol* 25 (CD ROM).

Thorburn PJ, Park SE and Biggs IM (2003b). Nitrogen fertiliser management in the Australian sugar industry: strategic opportunities for improved efficiency. *Proc Aust Soc Sug Cane Technol* 25 (CD ROM).

Thorburn PJ, Probert ME, Lisson S, Wood AW and Keating BA (1999). Impacts of trash retention on soil nitrogen and water: an example from the Australian sugarcane industry. *Proc S Afr Sug Technol Ass* 73: 75-79.

Thorburn PJ, van Antwerpen R, Meyer JH and Bezuidenhout CN (2002). The impact of trash management on soil carbon and nitrogen. I: Modelling long-term experiment results in the South African sugar industry. *Proc S Afr Sug Technol Ass* 76: 260-268.

Vallis I, Hughes RM, Ridge DR and Nielsen P (1994). Improving nitrogen management in sugarcane in southern Queensland and northern New South Wales. SRDC Final Report (CSC2S).

van Antwerpen R, Thorburn PJ, Horan H, Meyer JH and Bezuidenhout CN (2002). The impact of trash management on soil carbon and nitrogen. II: Implications for sugarcane production in South Africa. *Proc S Afr Sug Technol Ass* 76: 269-280.

Wood AW, Bramley RGV, Meyer JH and Johnson AKL (1997). Opportunities for improving nutrient management in the Australian sugar industry. pp 253-266 In: Keating BA and Wilson JR (Eds). *Intensive Sugarcane Production, Meeting the Challenges Beyond 2000.* CAB International, Wallingford.

Wood AW, Schroeder BL and Stewart RL (2003). The development of site-specific nutrient management guidelines for sustainable sugarcane production. *Proc Aust Soc Sug Cane Technol* 25 (CD ROM).