OPPORTUNITIES FOR IMPROVING THE EFFICENCY OF USE OF NITROGEN FERTILISER IN THE AUSTRALIAN SUGAR INDUSTRY

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Abstract

THE RECENT implementation of controls by the Queensland Government regulating the amount of nitrogen (N) and phosphorus (P) fertiliser that can be applied to sugarcane crops in north Queensland are aimed at protecting the Great Barrier Reef from excess nutrients derived from agricultural activities. It is timely to review recent improvements in the efficiency of nitrogen (N) fertiliser use and evaluate what opportunities exist for making further improvements. Nitrogen fertiliser application rates in the Australian sugar industry have shown a decreasing trend since the mid 1990s and when compared with cane yields have shown a steady improvement in fertiliser N use efficiency, expressed as tonnes cane/kg N. This paper discusses possible reasons for this trend including the adoption of a comprehensive program (Six Easy Steps) for supporting best practice nutrient management. Opportunities for further improvements in fertiliser N use efficiency are also reviewed. These can be divided into three main groups: more efficient plant uptake, more efficient N fertilisers and improved management practices.

Introduction

The Australian sugar industry faces new levels of scrutiny of its use of nutrients due to recent initiatives by the Queensland Government to regulate nutrient applications in order to protect the Great Barrier Reef from 'excess' nitrogen (N), phosphorus (P), sediment and chemicals which are assumed to be derived from agricultural activities along the Queensland coast (Anon, 2008). While these regulations appear to be driven by a political imperative to satisfy environment groups, this initiative has increased awareness of the need for a sustainable sugar industry with minimal off-site effects.

The new regulations require all sugarcane growers north of Rockhampton, in catchments draining into the Coral Sea, to undertake soil tests on blocks to be planted to sugarcane and interpret the soil test results using a nutrient calculator based on the 'Six Easy Steps' nutrient management guidelines (Schroeder *et al*., 2008b). While the

Queensland Government strategy to reduce nutrient use focuses on the outflow of both N and P into the Great Barrier Reef Lagoon, this paper only covers N usage. Nitrogen is undoubtedly the most important nutrient for sugarcane production and the prediction of how much N to apply to sugarcane remains the most difficult of all nutrient determinations, particularly under the highly variable soil and climatic conditions of the Australian sugar industry.

It is important to note that the Six Easy Steps is a comprehensive nutrient management program which focuses on all the essential plant nutrients and aims to have them all present at optimum and 'balanced' levels in sugarcane producing soils (Schroeder *et al*., 2006b).

This paper discusses the concept of N use efficiency and uses data on N usage for sugarcane in Queensland over the last 13 years to examine longer term trends in N use efficiency. Possible reasons for these trends are discussed, particularly the impact of best practice nutrient management programs and increased awareness among cane growers of sources of N other than fertiliser.

The second part of the paper explores prospects for further improvement in N use efficiency. These improvements can be divided into three groups: more efficient plant uptake of N, improved N fertilisers and management practices that improve the efficiency of N use.

Nitrogen fertiliser use efficiency

When fertiliser N is applied to soil it is generally not used efficiently, with crops seldom assimilating more than 50% of the N added as fertiliser. For sugarcane in Australia, studies using labelled ^{15}N fertiliser have indicated maximum recoveries in the crop and surrounding soil of just over 60% of N applied (Chapman *et al*., 1991; Vallis and Keating, 1994, Prasertsak *et al*., 2002).

The N that was not recovered is presumed to have been lost by a range of processes which include volatilisation, denitrification, leaching, erosion or runoff. The relative importance of each of these processes varies widely with soil type, position in the landscape and the amount and intensity of rainfall events. Other important factors include fertiliser form, placement, rate and timing of application and application method.

Lost nitrogen represents a serious economic loss to farmers; however the impact of the lost N on the environment is just as important. Gaseous losses of N via ammonia volatilisation and denitrification appear to be the dominant mechanisms for the loss of fertiliser N from Australian agro-ecosystems and result in the release of ammonia and the greenhouse gas nitrous oxide into the atmosphere (Chen *et al*., 2008).

We have a good understanding of ammonia volatilisation losses from urea applied to sugarcane trash blankets (Freney *et al*., 1992) and more recent studies on highly organic, acid sulphate soils used for sugarcane production in northern New South Wales have indicated a worst case scenario of extremely high N losses by denitrification (Denmead *et al*., 2005).

The efficiency with which N fertiliser is used by sugarcane can be expressed either as the 'N fertiliser utilisation index' expressed as kg N/t cane, or as the reciprocal 'fertiliser N use efficiency' expressed as t cane/kg N (Schroeder *et al*., 2010). In this paper we will focus on fertiliser N use efficiency.

Recent trends in nitrogen fertiliser use

Wood *et al*. (2008) recently used estimates of nutrient use based on data from Incitec Pivot Fertilisers sales and farmer surveys conducted by Herbert Cane Productivity Services to show that N use in the Herbert had declined by more than 25% between 1996 and 2006.

In this paper, Incitec Pivot Fertilisers data for sugarcane N use in the whole of Queensland from 1996–2008 have been used in conjunction with sugarcane production data. Data for N application rates have been related to the year in which the fertilised crop is harvested, so that it is possible to examine trends in fertiliser N use efficiency.

Application rates of N fertiliser declined steadily from 206 kg N/ha for the 1997 crop to 164 kg N/ha for the 2008 crop (Figure 1). A further reduction to 148 kg N/ha occurred for the 2009 crop, probably influenced by the very high fertiliser prices in 2008.

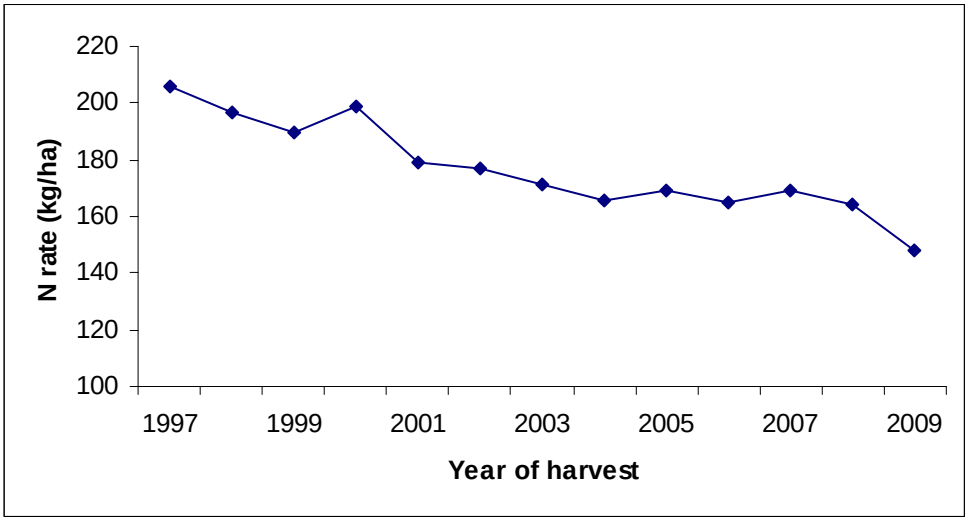

Fig. 1—Average N fertiliser application rates for sugarcane production in Queensland,1997–2009 crops.

No clear trends in fertiliser N use efficiency occurred during the period 1997-2003 due to the influence of adverse seasonal conditions and fluctuating crop yields (Figure 2). However, in 2004 N use efficiency exceeded 0.5 t cane/kg N for the first time and has remained above this level since then. It reached its highest level of 0.56 in 2005, with a high yielding crop and a favourable growing season, and 0.55 in 2009 with lower crop yields but reduced fertiliser application rates. The occurrence of

occasional, high yielding crops, such as in 2005, highlights the danger of basing N fertiliser application rates on cane yields in the previous year, as advocated in the N replacement strategy (Thorburn *et al.,* 2007a, b). The Six Easy Steps approach uses district yield potential to determine baseline N rates, and this ensures that the crop is able to access sufficient N fertiliser to support large crops during favourable growing seasons (Schroeder *et al.*, 2010).

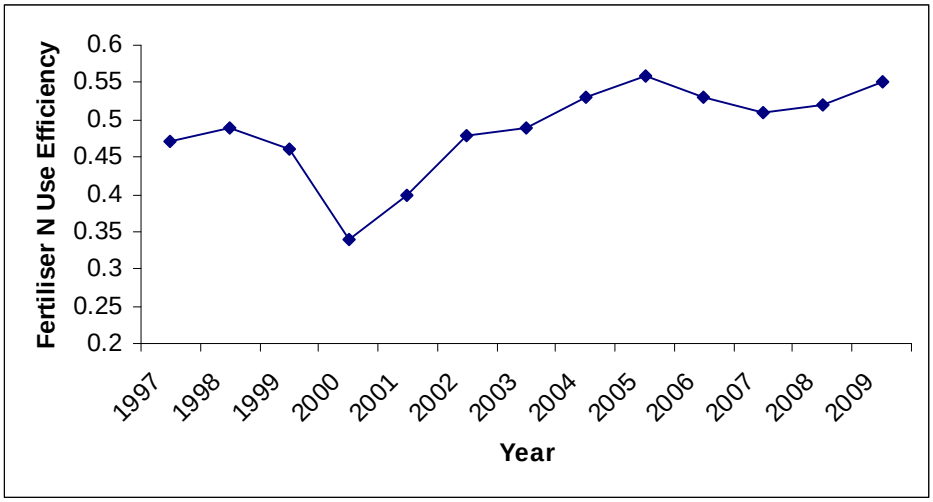

Fig. 2—Fertiliser N use efficiency (tonnes cane/kg N) for sugarcane production in Queensland, 1997–2009.

A number of factors have contributed to improvements in fertiliser N use efficiency during the last 13 years. We believe that these include:

- Promotion and adoption of modified industry N guidelines as an important part of the Six Easy Steps program instead of the previous generalised industry N guidelines. The Six Easy Steps clearly demonstrate to growers how N application rates can be calculated for each cane block using a combination of district yield potential and a soil N mineralisation index, with the latter related to the organic matter levels of their soils (Schroeder *et al*., 2005, 2009).
- Improved N management practices with increased attention paid to using the optimal form, application method, rate, placement and time of application of nitrogen fertiliser in each block based on dominant soil type.
- Increased use of soil and leaf testing and hence a better prediction of soil and crop nutrient requirements.
- Increased capacity to apply different amounts of nitrogen to each block within a farm, in relation to soil types or soil tests or both.
- Improved awareness of N inputs from other sources such as mill by-products, fallow legume crops and irrigation water.

- A trend towards using a wider range of nutrients than just nitrogen with a focus on balanced nutrition, leading to higher yields and hence more effective N use.
- Increased awareness of the different ways in which N can be lost and its potential contribution to offsite effects.
- Increased cost of N fertiliser in relation to sugar revenues resulting in N fertiliser forming a greater proportion of production costs than 15 years ago.
- A perception by growers that many years of green harvesting and trash retention have led to an increase in soil organic matter levels which result in greater amounts of N being recycled from crop residues.

Opportunities for further improvements in N use efficiency

There are several opportunities for achieving improvements in N use efficiency (NUE). These can be broadly divided into three groups: more efficient crop uptake of N, improved N fertilisers and management practices that improve the efficiency of N use.

More efficient crop uptake of N

There appears to be potential for the development of sugarcane crops with enhanced N use efficiency through cane breeding, variety selection and genetic modification. It is generally agreed that some sugarcane varieties differ in their response to N applications (Gascho *et al*., 1986).

In South Africa, cane varieties have been classified into one of three categories using the ratio of sucrose yield to N accumulation: efficient N-use responders, inefficient non-responders or inefficient responders (Schumann *et al*., 1998). These findings indicate that benefits may be derived from applying variety-specific N recommendations to the current suite of cane varieties in the South African sugar industry (Meyer *et al*., 2007).

Nitrogen use efficiency within crop plants is a complex trait which is a combination of the efficiency with which a crop can acquire soil and fertiliser N and the internal efficiency of the crop in using N to produce biomass and crop yield. The genetic variation in both acquisition efficiency and internal-use efficiency suggests that there is potential for further improvements in NUE through conventional variety selection and marker-assisted selection.

Research within the CRC for Sugar Industry Innovation through Biotechnology has focussed on identifying traits which can be used to assist the selection of sugarcane genotypes with improved levels of nitrogen use efficiency (Robinson *et al*., 2007, 2008, 2009).

Much research has been conducted on potential N contributions from N-fixing bacteria living freely in the soil, those occurring in the rhizosphere of sugarcane and those found in the stems of certain sugarcane varieties. In Brazil, where fixation of N within the sugarcane plant has been identified by diazotrophic bacteria such as *Glucanacetobacter diazotrophicus*, fertiliser recommendations now allow for N

fixation of up to 60 kg N/ha/year. While endogenous bacteria have been isolated from sugarcane in Australia (Li and MacRae, 1991, Chapman *et al.*, 1992) similar levels of N fixation to Brazil have not been achieved using current management practices (Biggs *et al*., 2000).

It has been suggested that the ability of these and other N-fixing bacteria to colonise the rhizosphere and inner tissues of sugarcane may be inhibited by a range of factors including soil fertility, nutrient availability and high N application rates (Fuentes-Ramirez *et al*., 1999; Baldani *et al.*, 2002).

It remains to be seen whether the successful improvement in N use efficiency achieved in Brazil through biological N-fixation can be successfully applied to sugarcane production in Australia.

More efficient N fertilisers

N fertilisers predominantly contain N in the form of ammonium, nitrate or urea. Specialty products that are essentially modifications of the above will continue to be produced provided they deliver cost-effective improvements in N use efficiency. Such products include granular or liquid formulations, controlled release fertilisers and products containing urease and nitrification inhibitors.

Numerous investigations have shown conclusively that surface applications of urea to a sugarcane trash blanket can, under certain conditions, result in substantial losses of nitrogen by ammonia volatilisation (Wood *et al.*, 1990; Freney *et al*., 1994). Rainfall of more than 15mm was found to be sufficient to dissolve the urea and wash it into the soil surface, thus reducing losses (Prammanee *et al*., 1989).

While moisture is an important factor in regulating N volatilisation losses from urea, the composition of the fertiliser mixture can also be important. Kong *et al*. (1991) found that ammonia volatilisation losses were greater from mixtures of urea and muriate of potash than from urea alone, due to the alkalinity of the muriate of potash. Similarly, Obcemea *et al.* (1993) found that volatilisation losses were reduced when mixtures of urea and ammonium sulphate were used, due to the acidity of the ammonium sulphate.

Concerns about N volatilisation losses have led to the commercial development of alternative products to urea for surface application with a lower volatilisation potential, such as mixtures of calcium ammonium nitrate and ammonium sulphate.

A range of liquid nitrogen-based fertilisers are also available and can be rapidly applied using multi row applicators. Rainfall simulation studies in the Mackay region have shown no significant differences in N losses by runoff from liquid fertiliser applied to the trash surface and granular urea applied beneath the soil surface (Masters *et al*., 2008).

The supply of N by a single application of slow or controlled-release fertiliser should be sufficient to satisfy plant requirements and maintain relatively low concentrations of mineral nitrogen in the soil at any particular time. Controlled release fertilisers have the potential to reduce N losses, improve N use efficiency and

yields (Shoji *et al*., 2001). Trials in Australia have demonstrated that polymer-coated urea products were effective in reducing nitrous oxide emissions from sugarcane soils (Wang *et al,* 2008) and ammonia losses when applied to the surface of sugarcane trash blankets (Obcemea, 1994).

Urease inhibitors are widely used for slowing down the rate of urea hydrolysis and inhibiting N losses by ammonia volatilisation. Obcemea (1994) compared the effectiveness of different urease inhibitors and found that cyclo hexylphosphoric triamide (CHPT) and N (n-butyl) thiophosphoric triamide (NBPT) were both effective in inhibiting hydrolysis of urea when applied to sugarcane crop residues. Cantarella *et al*. (2007) also found that NBPT with urea contributed to lower ammonia losses when applied to sugarcane trash in Brazil but that its effects were short-lived and relatively ineffective during long dry periods in winter.

Nitrification inhibitors maintain N in the soil as ammonium and slow down or prevent its conversion to nitrate and thus have potential to reduce N losses by both denitrification and leaching. One nitrification inhibitor, dimethylpyrazol phosphate (DMPP), was found to be relatively ineffective in reducing nitrous oxide emissions in field plots at both Murwillumbah and Mackay but significantly reduced emissions in fertilised chambers (Wang *et al*., 2008). Further evaluation is occurring in trials located in the Tully, Burdekin, Proserpine, Bundaberg, Maryborough and northern New South Wales regions on soils where N losses by denitrification or leaching are likely to be high.

Management practices that improve the efficiency of N use

Through a series of regionally-based short courses (Schroeder *et al*., 2008a) a range of management options are being suggested for reducing N losses. For example:

To reduce N volatilisation losses the following management options are suggested:

- apply urea into soil beneath trash blanket
- if urea is applied to the soil or trash surface
    - apply on or near the cane row
    - apply just prior to rain or irrigation
    - consider using mixture of urea and ammonium sulphate
    - consider use of urease inhibitors or polymer-coated granular urea
    - delay application until cane is around 50cm tall
    - consider sources of N other than urea that are less prone to volatilisation losses.

To reduce denitrification losses the following management options are suggested:

- improve surface drainage
- consider use of mounded rows

- consider splitting N applications where waterlogging occurs frequently
- take note of climate and weather forecasts to adjust N application strategies.

To reduce leaching losses the following management options are suggested:

- minimise tillage
- use plants such as fallow legume crops to store N
- consider splitting N application on permeable soils
- take note of climate and weather forecasts to adjust N application strategies.

While splitting N fertiliser applications represent a sensible strategy for reducing N losses by both leaching and denitrification, very little benefit in yield has been measured in sugarcane crops where this practice has been employed (Keating *et al.*, 1993). This conclusion has been supported by more recent trial work on poorly drained soils in the Rocky Point mill area where significant N losses by denitrification were measured, although there was some reduction in nitrous oxide emissions with split applications at higher N rates (Kingston *et al*., 2008, Allen *et al*., 2008).

Site-specific N management is a sound strategy for growers to use to improve the efficiency of N use. This is possible where soil tests are available for each cane block or where growers have access to a soil map and reference booklet containing soil specific management guidelines. Soil reference booklets for the Johnstone, Herbert, Proserpine and Bundaberg districts are now available and further booklets are in production (Schroeder *et al.*, 2006a, 2007a, 2007b, Wood *et al*., 2003).

Precision farming technologies and variable rate fertiliser applicators are available to vary N fertiliser applications continually across a field. This raises the possibility of achieving similar yields to those obtained with standard uniform management with a reduced amount of N fertiliser, or achieving higher yields with the same amount of fertiliser.

The specific technologies to do this are available but are not yet widely used, mainly because of uncertainties about the accuracy and profitability of this approach. For example, on-the-go sensors for assessing soil organic matter and soil nitrate status are being developed and could be used for deriving N management prescriptions across a cane block (Adamchuk *et al*., 2004).

Trickle irrigation and N fertigation without runoff provide growers with the opportunity to control the supply of N to the crop and ensure that crop recovery of N is enhanced and losses by leaching or denitrification are reduced. Trickle irrigation trials conducted near Fairymead Mill near Bundaberg have shown that it may be possible to reduce N application rates to around 75% of the industry standard (Dart *et al*., 2000).

Leaf analysis has been used to great advantage in determining the nutrient status of sugarcane in South Africa and is widely accepted as a means of improving the effectiveness of fertiliser use. Similar benefits could be achieved in the Australian

sugar industry provided a rapid turn-around time can be achieved between sampling and receipt of nutrient recommendations (Schroeder *et al*., 1999). An alternative approach to assist N fertiliser decision making is to monitor the N composition of shredded cane at sugar mills using rapid NIR analysis (Keating *et al*., 1999).

Since many combinations of farming systems and management practices exist, it is difficult to study all possible combinations.

Computer models such as APSIM-Sugar have been developed to simulate crop growth and assess the impacts of different management practices on N losses and N use efficiency (Keating *et al*., 1994, 1997). The advantage of such models is their ability to integrate biophysical variables, soil and water processes and management practices. Models can be used to consider trade-offs between economic and environmental considerations and assist with decision making for both prescriptive and corrective N fertiliser management.

Conclusions

Substantial changes have occurred in the last 10–15 years in the amount of N fertiliser used for sugarcane production and the efficiency with which it is used by the crop. In their review of nitrogen management for sugarcane at the Sugar 2000 Symposium, Keating *et al*. (1997) stated that 'an N rate higher than current recommendations is used on a significant proportion of farms.'

Similarly, Thorburn *et al*. (2003) stated that 'for more than a decade, N fertiliser use has been greater than (almost double) that required to produce the actual cane (and sugar) yields obtained in the Australian sugar industry, with deleterious consequences for productivity, sugar quality and environmental impacts in sugarcane growing areas.'

With comments such as these, it is not surprising that the Queensland Government formed the perception that the sugar industry was 'wasting' fertiliser N and that there was an urgent need to impose limits on the amount of nitrogen that should be applied in order to 'save' the Great Barrier Reef.

Average N rates have now fallen below the baseline application rates specified in the Six Easy Steps and fertiliser N use efficiency is close to its highest level in the last 40 years. However, a number of opportunities for further improvements in fertiliser N use efficiency remain and these will become increasingly attractive to growers with advances in technology.

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