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Final report to the Sugar Research and Development Corporation CTA007 A modelling framework to integrate research on nitrogen management of sugarcane

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CTA007: A modelling framework to integrate research on nitrogen management of sugar cane.

Nitrogen in Sugar Systems.

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PROJECT DATES: Commencement 1-7-92 Completion 30-6-96
2. Non-technical Summary

This project used a measurement and modelling approach to explore the processes controlling nitrogen supply and losses in the crop and soil elements of sugarcane production systems. Measurements took place both in the field and laboratory. These measurements, together with data collected from other sugarcane research projects in Australia and overseas, lead to the development of the APSIM-Sugarcane simulation model. This model captures the main elements of our understanding of sugarcane growth, yield, N uptake and utilisation and water use. APSIM is a modular modelling system, and the Sugarcane module is compatible with other APSIM modules of soil processes and crop management.

Within the life of this project, APSIM-Sugarcane was used to investigate N management strategies in sugarcane production systems. A major outcome of these modelling studies was the recognition of the potential for substantial N losses via leaching in situations where N fertiliser inputs exceeded crop demands.

This project drew together different threads in nitrogen research on sugarcane for the first time. Prior to this, the focus was on either empirical “rates and dates” experiments, which while underpinning current N fertiliser recommendations, were not advancing our understanding of N in the crop-soil system, and on studies of particular N processes (e.g. volatilisation or mineralisation), which were not integrated with one another or with the broader system performance.

The project stimulated a number of other activities that are now the focus for N research in the Australian sugarcane industry. These activities included:
- assessment of nitrate contamination in groundwaters associated with sugarcane production areas (e.g. LWRRDC Project CTC6, SRDC Projects on nitrates in groundwater)
- use of amino-N levels in cane stems at the mill at harvest time as an indicator of N supply on the farm (e.g. SRDC projects CTA029 and CTA045)
- long-term implications of trash retention on N supply to sugarcane crops (e.g. SRDC project CTA22)

The current research activity on nitrate contamination of groundwaters and N supply in trash blankets are making use of the modelling framework developed in this project.

In addition to use of the APSIM Sugarcane model for nitrogen research, it has also proved useful in other sugar R&D activities, most notably irrigation management.

3. Background to the Research Project

Nitrogen research within the Australian sugar industry has a long history. The first reports of fertiliser trials on cane appeared in the 1930’s and the emphasis through until the 1950’s was to encourage growers to use fertilisers to replace nutrients lost in the removed cane and burnt trash.
From the 1950’s until the 1980’s, the emphasis shifted to fertiliser rate trials aimed at developing recommendations for optimal rates, forms, timing and placement of fertilisers. This work lead to the recommendations for N fertiliser rates that are still in place today (Calcino 1994).

From 1987 onwards, the emphasis in N research shifted to the study of individual N processes in the crop-soil system. Volatilisation was extensively studied by Freeny, Denmead, Wood and colleagues. These studies showed how substantial gaseous N losses could occur if fertiliser products such as urea were applied to soil or trash surfaces and were exposed to dew or light rainfall. While this work made growers very aware of N losses, it was to possible to determine the significance of these losses to crop yield and other aspects of the N balance. At this same time, other researchers were making detailed studies of N uptake and recovery in cane crops (e.g. Vallis and colleagues in CSC2s). These studies relied heavily on use of stable isotopes on nitrogen to track the fate of N in the crop and soil. They showed that the recovery of N fertiliser by the sugarcane crop was relatively low (25 to 50%) in the year of application and that a significant proportion (20 – 40%) of the applied N was unaccounted for, presumably lost via leaching, denitrification and/or volatilisation.

In 1992, when this project was commenced, there was concern that nitrogen research for the sugarcane industry in Australia was fragmented and lacking in an integrative focus or capability. While the strategic research that was underway was generating new information on individual processes, there was no way in which the significance of this process work could be determined. In addition, the focus of the work to date had been maximising cane and sugar yields and minimising grower’s input costs. There had been little consideration given to the implications of nitrogen management on the soil resource base and on the ecosystems that surround the sugar industry.

4. Objectives of the Research Project

The aims of this project, as stated at its inception were:

... to make nitrogen research on sugar cane more efficient and more effective by developing tools to:

(1) extrapolate research results in both space and time.
(2) evaluate risks and returns of management and policy options.
(3) identify gaps in understanding and new research opportunities.

This was to be achieved by:

(1) The conduct of experiments to test and further develop models of nitrate leaching.
(2) Using these data as well as existing research results on other processes, to develop and test sub-models of the major nitrogen loss, transformation and uptake components of the nitrogen cycle.
(3) Linking these sub-models into a cropping systems framework.

The model was thought to have a role in the analysis of questions such as:
The better matching of N rates to soil types, soil fertility status and cane yield potential.

Assessment of options for altered timing or splitting of N fertiliser application.

Evaluation of the options open to farmers in relation to N fertiliser placement.

Evaluation of the risks of losing nitrate through leaching on different soil types.

These aims remained unchanged throughout the life of the project, although the applications focus evolved more towards the questions raised in (1), (2) and (4) above.

5. Research Methodology

The research methodology consisted of experimentation, model construction, model testing and model application. The experiments monitored N in the soil-crop system over a first and second ratoon crop upon which were imposed a range of N fertiliser and irrigation treatments. Data used in model construction and testing came from both other published and unpublished sources and from new experimentation. The field experimentation was located within the Bundaberg district while laboratory studies took place in Townsville using intact soil cores collected in Bundaberg.

Model construction made use of the APSIM (Agricultural Production Systems Simulator) framework. The soil water, soil nitrogen and surface residue modules of APSIM were pre-existing and made an essential contribution to this project. The SWIM module (water and solute movement) was also pre-existing (developed by CSIRO Division of Soils), but it was interfaced to APSIM for the purposes of this project. The new model construction was contained within the Sugarcane module.

In addition to the technical objectives of the project, effort was made to build the collaborative relationships amongst various individuals and organisations working on nitrogen management in sugarcane. These efforts took the form of a number of nitrogen workshops detailed in the Appendices.

Further details of research methods are contained in the Appendices, as outlined in Table 1.

6. Detailed Results

Results from the experimentation, model testing and model application activities are contained in the various publications and reports produced as part of this project (Appendices 1 to 19). Details of the major contents of these Appendices are provided in Table 1.
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<tr>
<th>Item</th>
<th>Appendices</th>
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<td>1.</td>
<td>Outlines yield and nitrogen uptake data from Bundaberg experiments.</td>
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<td></td>
<td>4.</td>
<td>Information on solute leaching experiments in Bundaberg</td>
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<td>Laboratory experiments</td>
<td>2.</td>
<td>Provides details of the leaching experiments conducted on undisturbed soils from Bundaberg and Macknade sites.</td>
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<td>Model construction and testing</td>
<td>3.</td>
<td>Details the interfacing of the SWIM water and solute movement module to APSIM</td>
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<td>Conference papers outlining the development of APSIM Sugarcane</td>
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<td>Examines approaches to modelling the sugarcane crop</td>
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<td>Reports on work arising from the visit of Prof. Bill Parton, in which the CENTURY model was adapted to model long term changes in soil organic matter in sugarcane systems. Lead onto the development of a similar capability in APSIM.</td>
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<td>Model application</td>
<td>8</td>
<td>The second paper in the journal series on APSIM Sugarcane, focusing on model application</td>
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<td></td>
<td>11</td>
<td>The major synthesis paper (Sugar 2000 Symposium) coming out of this project. Considers issues of nitrogen management in intensive agricultural systems, focusing on sugarcane in Australia.</td>
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<td>Explores N fertiliser management strategies in relation to irrigation inputs.</td>
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7. Discussion of Results

A very diverse range of work was done under the auspices of the project csc7s. This work is reported in the 19 publications and 2 workshop reports contained within the Appendices to this report.

There were two key outputs from the project, namely (i) a comprehensive sugarcane simulation modelling capability and (ii) insights into the significance, process and management of nitrogen in sugarcane production systems.

7.1 Sugarcane simulation modelling capability.

This achievement is reported in full in a number of the Appendices (see Table 1). The critical report is that of Keating et al (1999) in which the sugarcane module is formally describe and its performance over a diverse range of datasets from Australia, South Africa and Hawaii is presented. The abstract of this paper is reproduced below.

"Research on more productive and sustainable sugarcane production systems would be aided by a comprehensive simulator of the sugarcane crop that is cognisant of a broader crop-soil-management system. A sugarcane crop model is described that can be deployed in the APSIM framework for agricultural systems simulation. The model operates on a daily time step, grows a leaf canopy, uses intercepted radiation to produce assimilate, and partitions this assimilate into leaf, structural stalk and sugar. The crop physiological processes represented in the model respond to the radiation and temperature environment and are sensitive to water and nitrogen supply. The model simulates growth, water use, N accumulation, sugar dry weight and fresh cane yield for plant and ratoon crops in response to climate, soil, management and genotypic factors.

The model was developed on 35 datasets from Australia, Hawaii, South Africa and Swaziland, covering a wide range of crop classes, latitudes, water regimes and nitrogen supply conditions. Coefficients of determination for model predictions compared to observed data included 0.79 for LAI, 0.93 for crop biomass, 0.83 for stalk sucrose and 0.86 for N accumulation in above ground tissues. The particular strengths of this model are discussed in the context of agricultural systems simulation."

<table>
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<th>14</th>
<th>Reviews the available information on uptake and loss of nitrogen in sugarcane crops.</th>
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<tbody>
<tr>
<td>Collaboration, networking and training</td>
<td>Contains the proceedings of the nitrogen workshop held at the outset of the project</td>
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<tr>
<td>21</td>
<td>Contains the training notes and background material for the workshop held in Oct 1996 titled, &quot;Modelling nitrogen in sugarcane systems&quot;</td>
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</table>
The performance of the model over all these datasets is summarised in Figure 1.

A number of the 35 datasets used to build and test the Sugarcane module were particularly important in getting the nitrogen aspects of the module developed and tested. One example of such a dataset is that gathered as a key activity in csc7s, namely the experiment that took place on the Schulte farm in Bundaberg, over the 1992-1995 period (Figure 2).
Figure 2: Observed (symbols) and predicted (lines) time-courses of nitrogen accumulation in green biomass, millable stalk, and green leaf (g m-2) in three datasets varying in N supply regime. (from Keating et al 1999).

Further details of the sugar module itself or its application to research and development issues can be found in Keating et al. (1999) and Lisson et al (2000) respectively. Copies are provided in Appendices 7 and 8.

7.2 Nitrogen in the sugarcane production system

The major effort at synthesis of the insights coming out of model application to nitrogen issues in sugarcane production systems was in the paper delivered to the Sugar 2000 conference in 1996. The abstract for this paper went as follows ;
"The substantial increase in N fertiliser used in the Australian sugar industry over the last 40 years is mirrored in intensive cropping industries world-wide. Whilst enabling higher production, downsides of increasing N fertiliser input have included acidification, contamination of ground and surface water and enhanced greenhouse gas emission.

Issues of N requirement, N loss and opportunities for improved N management are explored in this paper with the aid of a crop-soil simulation model (APSIM-Sugarcane) which encapsulates what we know of N supply and utilisation in sugarcane systems. While the study focuses on sugarcane in Australia, the principles established are relevant to other intensive cropping systems in other parts of the world.

The consistent theme through the analysis is the way in which decisions on N fertilisation rate affect the balance between production, profit and environmental impact. Optimum N rates are identified and related to other factors influencing production. Response curves are estimated to be very flat once the optimum is reached and there is little direct economic incentive to better match N fertiliser management to soil and climate condition and crop requirement. There are, however, major gains to be made in reducing the potential for N leaching loss by eliminating the worst cases of over-fertilisation. We conclude that changes in N fertilisation practice for sugarcane in Australia are more likely to come from an environmental imperative than an economic one."


This paper went on to develop a case study of nitrogen fertilisation of cane crops in the Ingham district.

The case study was interpreted as follows (extracts from Keating et al 1997):

"There is a long history of agronomists and economists studying yield / fertiliser responses (e.g. Colwell, 1970; Dillon and Anderson, 1990; Bullock and Bullock, 1994). The bio-economic literature consistently refers to the relative insensitivity of economic returns at levels of input around the optimum (Anderson, 1975; Jardine, 1975; White, 1975). In other words, the response functions are relatively flat around the optimum and there is little to be gained by investing management and research resources in ‘fine-tuning’ N management. Jardine (1975) demonstrated that in many situations, one half the optimal fertiliser rate generates 90% of the gross margins. Anderson (1975) summed up the economic argument with respect to optimal levels of decision variables succinctly in the quote: 'precision is pretence and great accuracy is absurdity'.

Our simulation studies are consistent with this view. Fertiliser N rates between 97 and 160kg ha\(^{-1}\) generated returns above 95% of the optimum. The higher the value of the product, relative to the costs of the fertiliser inputs, the greater the insensitivity of return to the precise level of fertiliser input. These economic forces contribute to the phenomenon that the ratio of N input to N offtake in the harvested product increases substantially as one moves from extensive to intensive agricultural systems.

Use of ‘supra-optimal’ levels of N fertiliser by many canegrowers in Australia would appear to stem from:

1. Growers appreciating that returns are very insensitive to N rates above the economic optimum, but are more sensitive to N rates below the optimum.
2. Growers perceiving levels of risk and uncertainty that encourage the use of rates high enough to ensure sub-optimal inputs never arise.

If economic returns were the only consideration in determining $N_{opt}$ for sugarcane, there would be little case for attempting to fine tune rates. However, increasing concern for the resource base and the environment will motivate growers to ensure that N fertilisation rates are not excessive. Given these opposing forces, we argue that more precise N fertiliser management, that better reflects soil supply and crop demand, is a goal worth striving for in the sugarcane industry. The simulation (Fig. 3) highlights the potential for N losses with excessive N use. $N_{opt}$ is closely related to likely cane yield and there are opportunities to better promote this concept within the industry. For N applied efficiently (e.g. no volatilisation losses), the rule of thumb of 1.4kg N t$^{-1}$ of cane should be adequate for the first 100t of crop and 1.0kg N for each tonne above that (Fig. 4). The simulation study also reinforces the existing recommendations that prescribe lower N rates for more fertile soils and plant crops (data not shown).

![Fig. 3. Average gross margins and N leaching simulated in a plant and 4 ratoon cycle at Ingham, Qld over 100y of climate data. [Hatched area indicates a range of N rates that achieve both optimal economic returns and acceptable N leaching losses]

![Fig. 4. 'Rule of thumb' measure of N fertiliser required to produce one tonne of cane. [Estimated from simulated $N_{opt}$ and cane yield over 100 years at Ingham, Qld. Points denoted as current recommendations relate to industry recommendations (Calcino, 1994) for 100 and 150t ha$^{-1}$ crops]
The conclusions from the simulation study differ from current industry recommendations more in degree than substance. Whilst simulated $N_{opt}$ values are c. 20% lower than current recommendations we suspect the latter have a degree of risk avoidance built into them, and were developed before there arose an environmental dimension to the $N$ fertilisation issue. Some growers appear to opt for their own element of insurance by using higher than recommended rates.

While $N$ process research, and the model construction that has accompanied it, has provided results largely consistent with current recommendations, its value lies in providing a more comprehensive understanding of dynamics of $N$ within the sugarcane crop-soil system. This understanding provides the basis for both improvements in technology and the knowledge-base of growers and advisers.

8. Implications and Recommendations

Keating et al (1997) identified the following future directions for $N$ research and management in sugarcane:

"We see four directions for future work............

Firstly, assessment of any negative impacts on the resource base or the environment. Such work is underway in a number of locations in the Australian sugar industry, notably for surface waters in the South Johnstone (McShane et al., 1993) and Herbert (Bramley and Johnston, 1997) catchments, and for groundwaters in Bundaberg (Keating et al., 1997a).

Secondly, expanding the knowledge that growers themselves have of the $N$ cycle and the implications of excessive $N$ fertilisation not only in terms of their production/profits, but also in terms of any negative effects on their soils or the wider environment. We see this as a priority and believe the models can contribute to this learning experience.

Thirdly, achieving better efficiency of $N$ use through new products or methods of application. Nitrification inhibitors and slow release fertiliser formulations have offered promise for some time but to date the economics appear unattractive for widespread application. Trickle irrigation and fertigation provide a quantum leap in the control growers have over $N$ supply but < 1% of the crop is trickle irrigated. We believe this area will grow and offers good prospects for control of $N$ leaching loss in sensitive areas.

A fourth aspect that warrants attention is the monitoring of crop or soil $N$ status as a basis for improved decision making. Crop monitoring has proven valuable in various crop systems, e.g. sap nitrate in cereal (Elliot et al., 1993) and horticultural crops (Olsen and Lyons, 1994), and the chlorophyll meter in maize (Schepers et al., 1992). Logistical difficulties with $N$ application during later growth and the potential for such applications to impact negatively on CCS suggest there is limited scope for within-season tactical adjustments to $N$ management of sugarcane. The insensitivity of the system to current fertiliser application because of the 'buffering' role of mineralisation of soil organic matter as a source of $N$ for the current crop (Keating et al., 1993) reinforces this judgement. Strategic assessments at a block-specific level as a basis for next year's crop hold greater promise. Soil testing forms part of the South African fertiliser recommendation scheme (Moberly et al., 1984). However, predictive tests remain unproven for sugarcane in Australia. Current research in Australia indicates that the analysis of nitrogenous compounds in sugarcane juice at the mill holds promise as a basis of identifying under- or over-fertilisation (B.A. Keating, 1997, unpublished data).
Investment in additional information specific to a particular management decision (e.g. crop or soil testing prior to fertilising a particular paddock) can be viewed as an effort to reduce uncertainty. The benefit of such an investment will depend on the cost of gathering information relative to the benefit for improved decision making. With respect to the latter, the flatness of the economic response curves around the optimum has limited the attractiveness of elaborate monitoring schemes in other systems, e.g. wheat / lupins in Western Australia (D. Pannell, pers. comm.) and wheat in the north-east grains region, (P. Hayman, pers. comm.). However, the need to reduce negative consequences for the environment may mean that such investment is warranted for N fertiliser management of sugarcane.


9. Intellectual property

The APSIM modelling framework remains the intellectual property of APSRU, a consortium made up of CSIRO Tropical Crops and Pastures and Qld DPI.

SRDC support has contributed to the development of the Sugarcane Module to APSIM, and hence intellectual property ownership of this module is shared between CSIRO and SRDC. On the basis of funding provided during CSC7s, we estimate the equity breakdown to be 80% CSIRO and 20% SRDC.

The APSIM model (including the Sugarcane module) is made available to other researchers for non-commercial use under a licence arrangement. The licence specifies expectations for training and support (for which there may be cost recovery applied) and the nature of the application. It also contains provisions to ensure the integrity of the modelling software and to protect the APSRU partners from liability claims.

10. Project Publications


List of Appendices


