Benefits of sub-surface application of nitrogen and water to trickle irrigated sugarcane

Peter Thorburn[1], Jody Biggs[1], Keith Bristow[2], Heidi Horan[1] and Neil Huth[1]

[1]CSIRO Sustainable Ecosystems and CRC for Sustainable Sugar Production, 120 Meiers Rd, Indooroopilly Qld 4068. Email Peter.Thorburn@csiro.au
[2]CSIRO Land and Water and CRC for Sustainable Sugar Production, PMB Aitkenvale, Townsville Qld. 4814.

Abstract

Fertigation can be a more efficient means of applying crop nutrients, particularly nitrogen (N), so nutrient application rates should be reduced in fertigated crops. However, there is little information on the extent of the possible reduction in N application for many fertigated crops, particularly sugarcane, which is one of the major row crops grown under trickle irrigation and the major crop grown in north eastern Australia. In this study, a cropping systems model (APSIM) was modified to represent sub-surface application of water and N to crops as an approximation of sub-surface trickle irrigation systems. The performance of the model was assessed relative to measurements from a five year sugarcane sub-surface trickle irrigation/fertigation N response experiment. Absolute cane yields were over-predicted, but relative response of yield to applied N was well predicted. The long-term response of sugarcane yields to a wide range of N application rates were then simulated for both the surface and sub-surface application of water and N. Simulations showed that the benefits of sub-surface application of water and N will be **either** a saving in N fertiliser for similar yield, as expected, or an increase in yield for similar N inputs. Whichever of these is most desirable will depend on the specific economic circumstances of the sugarcane production system.

Key Words

APSIM, drip irrigation, fertilizer, mineralisation, nitrate leaching, organic matter, simulation

Introduction

In common with all agricultural enterprises, the Australian sugar industry is striving to increase the efficiency of its resource use and reduce off site impacts of production. The industry is mainly located along the north eastern coastline of the country, in close proximity to environmentally sensitive areas (i.e., the Great Barrier Reef and World Heritage listed rainforests) and large numbers of people in regional cities. One option for increasing resource use efficiency in irrigated sugar production systems is the use of trickle irrigation (1, 2). During the 1990's, the area of trickle irrigated sugarcane (*Saccharum* spp. hybrids) in Australia increased substantially, from approximately 1,000 to 4,000 ha, although it is still a small proportion (< 2 %) of the total area of irrigated sugarcane. However, much of the increase in area was driven by a desire to increase irrigation application efficiencies and little attention has been paid to nutrient use efficiency.

It is commonly accepted that efficiency of fertiliser use can be higher in most crops when fertiliser is applied through a trickle irrigation system, especially sub-surface systems. Such gains in efficiency would be particularly useful for the application of nitrogen (N) to sugarcane (3), because N is the main nutrient of environmental concern and sugarcane requires large applications (up to 200 kg/ha) of N. While knowledge exists about N application rates in conventional management systems, there is little information on the optimum N rate for sugarcane where both irrigation water and N are applied through a sub-surface trickle irrigation system. It is possible that N application rates could be reduced by 25-50 % compared with conventional management (2, 3). As with most field experiments however, these experiments were conducted for a limited time (2-5 y) with a limited range of treatments; e.g., few or no conventionally irrigated and fertilised treatments to act as a control (2, 3, 4). Thus important questions still exist regarding the optimum management of N in trickle irrigated/fertigated sugarcane, and the advantages of such a system in comparison with conventional systems.

In an effort to address these questions, a cropping systems model (the Agricultural Production systems SIMulator; 5) that well predicts N responses in conventionally managed sugarcane (6) was modified to represent application of water and N to crops via a sub-surface trickle irrigation system, and the performance of the model assessed relative to experimental measurements (3, 4). The model was then applied to assess the long-term production and environmental benefits of applying N to sugarcane through sub-surface irrigation/fertigation. Strategies for optimising N management in fertigated sugarcane grown in north eastern Australia are described.

Methods

The APSIM modelling framework (5) was used, incorporating modules for soil organic matter, N, water (7) and crop residue (8) dynamics and sugarcane growth (6). In order to represent irrigation from sub-surface trickle systems, the soil water module, a layered water balance model, was modified to allow irrigation water (specified in mm) to be applied in any layer. Previously, irrigation could only be applied to the surface of the soil. There was no attempt to represent the two-dimensional nature of wetting from a trickle irrigation emitter. N fertiliser could be applied at any layer in the model.

The model was configured with seven layers to a maximum soil depth of 2 m. Model soil parameters were based, wherever possible, on data measured during the field experiment (3, 4). Soils in replicate blocks of the field experiment differed substantially, so each separate replicate block was modelled individually. Default parameter values for the variety Q124 (6) were used in the sugarcane model.

To perform simulations of the experiment, management data (3, 4) were used to specify details of sugarcane planting and harvest, and dates and amounts of irrigation and N fertiliser applications. The experiment was planted in September 1996 and each of the five crops was harvested at 12 months of age. In all plots, irrigation was applied daily (except during and soon after rain) through trickle irrigation tape buried 0.3 m depth in the soil. N fertiliser (urea) was applied through the trickle system (over four splits) at rates of 0, 80, 120, 160 and 240 kg/ha on ratoon crops, and 75 % of that rate on the plant crop. For the 160 kg/ha treatment (denoted N_{160}), fertiliser was also applied conventionally (by coulter at ~ 0.1 m depth) in an additional treatment. There were three replicates of each treatment. Plots were large (~ 0.2 ha), commercially grown and harvested.

In the simulations, N fertiliser (urea) and irrigation water were applied in layer 3 of the soil module, the layer corresponding to the depth of the trickle tape, in five of the six treatments. In the sixth treatment where N was applied conventionally, fertiliser was applied to the soil surface with irrigation water applied in layer 3. Climate data were taken from rainfall measurements made at the site and temperature and solar radiation measurements made ~ 3 km from the site.

Long-term simulations were performed to extrapolate the experimental N response results through time and to compare them with responses in a conventionally irrigated and fertilised system. Unlike the experimental crops which were 12 months long, a more common cropping cycle was adopted for the long-term simulations. Each crop cycle consisted of a 15 month plant crop (planted in early May) and four 13 month ratoon crops. Simulations were commenced in 1895 and run until 1995 (17 crop cycles). Weather data were obtained from the Australian Bureau of Meteorology. Eleven different rates of N fertiliser were applied, with the plant crop receiving 75 % of that applied to the ratoon crops. The N rates for the ratoon crops commenced with 0 kg/ha, incrementing by 30 kg/ha to a maximum of 300 kg/ha. The N was applied as urea. Irrigation water and N were applied at the soil surface to represent the conventional management system. For the sub-surface trickle irrigation/fertigation system, irrigation water and N were applied in layer 3 as in simulations of the experimental data.

Results

Simulation of experimental results

There was no significant yield response to applied N fertiliser in the plant crop, although there was in all subsequent crops (Figure 1). Yields of sugarcane in the field experiment were generally over predicted by the model, particularly in the second ratoon (2R) crop. This general over estimation was expected as the field experiment was conducted and managed on a commercial scale, and so subject to harvest losses, harvest damage, pest damage, lodging, etc; factors that are not considered in the model and are minimised in small plot experiments. Twice the average rainfall was received in the first three months of the 2R crop, and water was continually ponded on the soil surface of the experiment for much of this time (4). These conditions are likely to have damaged stools, through water logging, inhibiting the growth of the 2R and subsequent crops. Water logging is not represented in APSIM-Sugarcane (6), so this damage contributes to the over prediction of yields in the last three crops.

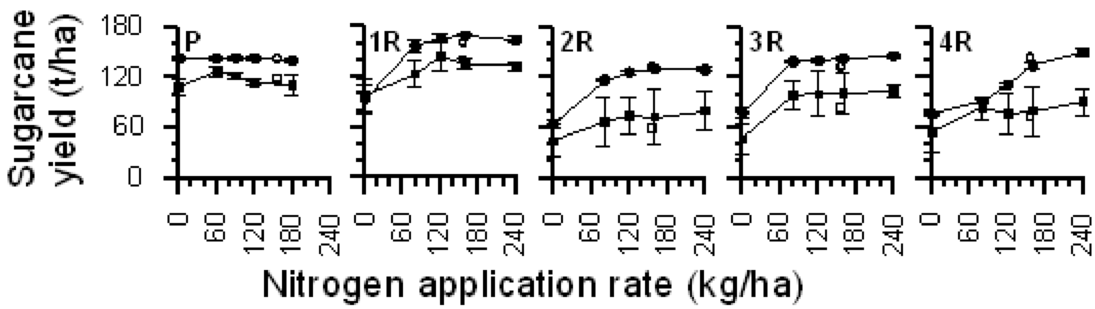

Figure 1. Mean measured (squares) and simulated (circles) response of sugarcane yields to different rates of N applied through a sub-surface trickle system in five crops. Open symbols represent the treatment were N was surface applied. The bars show standard errors of the means.

Even though yields were generally over predicted, the relative N response of the crop was well predicted in all crops (Figure 2). In the N_{160} treatment, measured and simulated yields were generally similar whether N was applied by fertigation or conventionally for the plant and 1R crops (Figure 1).

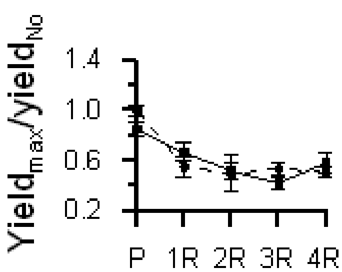

Figure 2. Measured (solid lines) and simulated (dashed lines) relative N response (i.e., the maximum yield relative to that in the treatment with no applied N) over five sugarcane crops.

Simulated impact of different nitrogen fertiliser application rates

For both irrigation/fertiliser systems, the simulated response of cane yield to N fertiliser application varied markedly between each crop (data not shown) in response to climatic differences over the different growing seasons. This variability did not overshadow the more consistent impacts of irrigation/fertiliser application management, and so mean yields for the five crops in each crop cycle were compared (three example crop cycles shown in Figure 2).

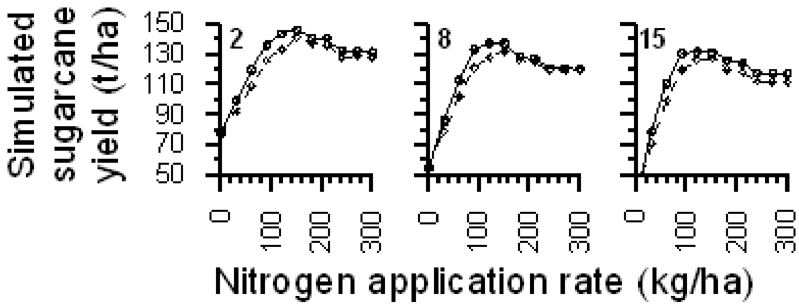

Figure 3. Simulated response of irrigation and different rates of applied N fertiliser when applied "con-ventionally" on the surface (diamonds, dashed lines) and at depth (circles, solid lines) in three crop cycles, the 2nd, 8th and 15th.

In most crop cycles simulated cane yields were similar in both conventional and sub-surface irrigation/fertiliser application at low and high rates of N application. Differences between the management systems tended to be confined to intermediate rates of N application, e.g., between 60 and 150 kg/ha. Maximum yields were simulated to occur at N application rates of 120-150 kg/ha in both management systems in all crop cycles, and were on average 5 % higher in the sub-surface irrigation/fertiliser system compared to the conventional system in all crop cycles.

Discussion

While the predictions of absolute sugarcane yield in the experiment were not accurate (Figure 1), the similarity in response of yield to applied N in both the simulations and the experiment in all crop cycles (Figure 2) was encouraging, and indicate that the modified model could be used to more broadly examine the response of sugarcane to application of water and N through trickle systems.

It is commonly assumed that because N can be applied more efficiently through sub-surface fertigation that N application rates can be decreased (1, 2). This was observed in the simulations: In the 8th crop cycle, for example, a maximum mean yield of 132 t/ha was achieved with the application of 150 kg/ha of N where irrigation and N were surface applied, while a similar yield was achieved with the application of 90 kg/ha of N where irrigation and N were sub-surface applied (Figure 3). Over all crop cycles, savings of N with the sub-surface application of irrigation and N were in the order of 10-40 % (data not shown), similar to those suggested previously (1, 2, 3, 4).

However, the philosophy behind reducing N applications in trickle irrigated crops implicitly assumes that yields in the conventional and trickle systems will be similar. Where water is applied through a well managed trickle system and system efficiency increases (through reduced deep drainage and evaporation from the soil), yields may increase in response to the increased **net** application of water. To realise these higher yields greater nutrient inputs, in the case of this study N, will be required (Figure 3). Thus, the sub-surface application of water and N creates a different system compared with surface application, and each system has a different N response. The simulations conducted in this study suggest the benefits of sub-surface application of water and N will be **either** a saving in N fertiliser for similar yield, or an increase in yield for similar N inputs. Whichever of these is most desirable will depend on the specific economic circumstances of the sugarcane production system.

Acknowledgements

Funding for this study was provided by. The experiment was established and maintained by Mike Smith, Ian Dart, Craig Baillie and Sam Stacey of Bundaberg Sugar, whose enthusiastic collaboration made the study possible. We are indebted to them, and to Dr Merv Probert for his valuable advice during the study.

References

(1) Thorburn, P.J., Sweeney, C.A. and Bristow, K.L. 1998. Proc. Aust. Soc. Sugar Cane Technol., 20:118-125.

(2) Ng Kee Kwong, K.F., Paul, J.P. and Deville, J. 1999. Exp. Agric., 35: 31-37.

(3) Thorburn, P.J., Dart, I.K., Biggs, I.J., Baillie, C.P., Smith, M.A. and Keating, B.A. 2002. Irrig. Sci., (In press).

(4) Dart, I.K., Baillie, C.P. and Thorburn, P.J. 2000. Proc. Aust. Soc. Sugar Cane Technol., 22: 230-235.

(5) McCown, R.L., Hammer, G.L., Hargreaves, J.N.G., Holzworth, D.P. and Freebairn, D.M. 1996. Agric. Systems, 50: 255-271.

(6) Keating, B.A., Robertson, M.J., Muchow, R.C. and Huth, N.I. 1999. Field Crops Res., 61: 253-271.

(7) Probert, M.E., Dimes, J.P., Keating, B.A., Dalal, R.C. and Strong, W.M. 1998. Agric. Systems, 56: 1-28.

(8) Thorburn, P.J., Probert, M.E. and Robertson, F.A. 2001. Field Crops Res., 70: 223-232.