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SRDC Research Project Final Report
Increased profitability and water use efficiency through best use of limited water under supplementary irrigation

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SRDC Research Project Final Report

Increased profitability and water use efficiency through best use of limited water under supplementary irrigation

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EXECUTIVE SUMMARY

It is hard to overstate the importance of water in the Australian sugar industry. Not only is water the most important factor limiting yields in the industry, it is the means by which nutrients and pesticides are transported below the root zone and off the farm. Community concerns over off site impacts and over the large amount of water used in agriculture, have increased during the life of this project. The project focussed on regions with limited water to tackle issues identified by the grower community. These concerns were largely to do with production and water use efficiency issues rather than environmental ones but the technology developed during the project will also reduce off farm impacts once it gets fully implemented. The two major issues addressed in the project, the timing of limited water and yield response to increased allocation, are as current as ever. Recent dry years particularly in the central region have again focussed attention on the importance of using limited water at the right time and on investing in increased water supply. A water recycling project in that region has made extensive use of the water production functions developed during the project. The capability developed during the project to apply water at the optimum time has been well received and has the potential to assist growers with seasonal planning of water use and to ensure that they use all their allocated water each year. Full and timely use of limited water will undoubtedly increase yields substantially when this technology is understood and applied on a wide scale.

Timing of limited water

Timing of limited water use was the main concern for growers and for the research during the first three years of the project when it was funded mainly by the Rural Water Use Initiative (RWUEI) of the QDNR&M. Two replicated experiments were established in October 2000 on private farms in the Bundaberg and Childers regions. The trials were designed in conjunction with the Bundaberg and Childers management committees of the Rural Water Use Efficiency Initiative (RWUEI). These committees selected the same four treatments for each trial. Two treatments were designed to compare what growers could produce from their limited water, with what scientists and their computer models could produce with the same limited water. An optimisation procedure called WaterSense, based on the APSIM Sugarcane model, was developed by the research team for the ‘competition’ umpired by the RWUEI committees.

The competition was a draw with equal yields and sucrose content in the first year, superior grower results in the second and superior WaterSense results in the third. Despite the difficulty in explaining the relatively low yields of the WaterSense treatment in the second year, the growers involved were impressed with the skill of WaterSense. The RWUEI extension officers and committee members from both Bundaberg and Childers requested that the scheduling tool be made available for general use.

WaterSense on the Web

The development of the web tool was fully described by Inman-Bamber et al (2004). Computers at CSIRO Davies lab in Townsville store historic climatic data obtained from the Bureau of Meteorology’s SILO database. These computers down-load current climate data every day from four AWSs operating in the Bundaberg/Childers region. One computer contacts a CSIRO server in Canberra at 10 min intervals to see if anyone has requested a job. The Canberra server supports the web pages which are used to enter details about the paddock, to check or alter rainfall and to initiate the necessary APSIM simulations which take about 40 min for each paddock. The subsequent optimisation is completed rapidly and an email is generated and sent immediately to the user. As far as is known this type of irrigation scheduling optimisation technique that was developed and tested experimentally for sugarcane has not been reported before, certainly not in sugarcane. A process is now underway to explain WaterSense to interested cane growers and advisors. Operation and presentation will be changed after consultation in order to improve the usefulness and accuracy of this tool.
Water production functions
In 2001 to 2003 experiments were conducted at Kalamia in the Burdekin to test the water production functions generated by the APSIM model which have been used extensively for decision support in irrigation and on-farm storage planning (Lisson et al, 2000). Allocations of 2, 4, 6, 8, and 10 ML/ha were scheduled by WaterSense so that each allocation was used in the best possible way. Well irrigated plots started to lodge in February in both years. Cane yield in February '02 was reduced in the low allocation treatments but by the June '02 only the 2 ML treatment had a reduced yield. All other treatments yielded about 140 t/ha. Lodging increased linearly with allocations up to 10 ML/ha in the 2002/03 experiment. Total aboveground biomass increased with irrigation up to 8 ML/ha in February '03 but differences were small and non significant in August '03. There was no gain in biomass in the fully irrigated treatment over this time while the gain in the 2 ML treatment was more than double even though irrigation for this treatment ran out in December '02.

These results have important implications for decisions about investment in irrigation infrastructure including on-farm dams. Estimates of yield response and profit from irrigation may be too high when considering increased allocations resulting from storages particularly in the higher range of allocations. The phenomenon of lodging and consequent yield loss due to irrigation increases the risk of investments in supplementary irrigation in a way that may not have been considered before.

Benefits of the project
The key benefit expected from this project is improved profitability from irrigated sugarcane due to more efficient timing of use of water and greater usage of allocated water albeit limited. A second benefit is more efficient investment in water storages on farm or in securing water allocations from off-farm sources due to the capability for improved water production functions produced by the project. A third benefit in some environments will be less drainage losses and leaching of nutrients resulting from improved timing of irrigation. An analysis of future benefits from this project by Agrtrans Research indicates that the investment in the project ‘appears to have been extremely sound. Given the assumptions made for low adoption, the investment in project CSE001 and part of CSE009 still shows an expected net present value of $ 1.7 m, a benefit-cost ratio of nearly 2 to 1, and an internal rate of return of over 9%.’

Benefits to the science of sugarcane production include new knowledge concerning crop physiology and crop modelling. Areas of sugarcane physiology that have been refined as a result of the project include responses of leaf and stalk extension to water stress, depth of root water extraction by sugarcane (up to 2.8 m), root water extraction coefficients and factors (soil, climate and crop) that favour lodging. The APSIM model has been improved due to the investment in this project. The project has resulted in eight publications in the national and international literature. A paper by Inman-Bamber and Smith (Water relations in sugarcane and response to water deficits. Field Crops Res. 92, 185-202, 2005) was in the top 10 most downloaded FCR articles in December quarter of 2005.

BACKGROUND

Water allocations in many sugarcane production regions are insufficient to make up the difference between crop water requirement and effective rainfall (Holden, 1998). Irrigation requirement varies from year to year because of the high variability in rainfall for the sugar industry. There are a number of questions arising from high rainfall variability. Firstly, is irrigation economically worthwhile and if so how much water is available for irrigation from existing surface and underground sources? Is it worth building on-farm or syndicate storages? At what point is increasing irrigation or allocation no longer profitable? What investment in irrigation infrastructure is required for the appropriate allocation and flexibility of irrigation? Once the system is in place how should limited irrigation be spread over the farm and within each paddock
over time? Answers to these questions depend on two basic characteristics of the soil-plant-climate system pertaining to the farm.

The first characteristic is the yield response to increasing allocations of water or ‘water production function’. In high rainfall conditions and deep soils the response to increasing allocation may be uneconomic after only a small amount of irrigation has been applied while in low rainfall conditions and shallow soils yield responses may be economic well beyond the limit imposed by restricted allocations. The second characteristic requiring definition is the nature of yield response to soil water deficits at different stages. If irrigation and rainfall is limiting, crop stress and consequent yield loss is unavoidable. How can limited irrigation be spread over the duration of the crop to maximize crop yield? Are there particular stages in the development of the crop that are more responsive to irrigation than others? These questions can only be answered when the physiological responses to water stress and soil hydraulic properties are known. Growers may have worked out the second characteristic reasonably well by trial and error over many years however it is unlikely that they would have had the opportunity to work out the value of increased allocation since they are mostly dealing with very limited quantities of water. The characteristics just described were highlighted as issues for research by growers at a Rural Water Use Efficiency Initiative (RWUEI) workshop held at Childers in June 2000 and research was consequently funded and undertaken to improve understanding about these issues.

Other issues raised at this workshop and at other grower meetings included, the carry over effect of water stress from one ratoon to the next, risk of water logging with irrigation and how to use limited water in the presence of fluctuating water tables.

OBJECTIVES

The objectives of this project towards increased profitability and water use efficiency was to:

1. Build on past research to develop guidelines to support tactical and strategic decisions regarding a) timing of limited water applications, b) water allocations to each paddock, c) extending ratoon life, d) making use of water upflow from water tables and e) withholding irrigation to reduce risks of waterlogging;
2. Further enhance sugarcane systems modelling capability;
3. Customize tools for industry; and
4. Work with extension officers in applying these tools in an action research context with industry.

All project objectives were achieved fully as outlined in the following sections.

METHODOLOGY and ACHIEVEMENTS

The structure of this section is based on the Objectives of the project (above) in order to describe how the issues listed in the Objectives were addressed and how each component of the Objectives was achieved. Many issues required a mixture of conventional field plot experimentation and modelling while in some cases only modelling was required or possible. The field experimentation was always based on the theoretical framework of the APSIM Sugarcane model. Thus the results of the field work contributed both directly to new knowledge about the issue under consideration and indirectly to all issues that were amenable to analysis through the APSIM-Sugarcane model. The results of field and simulation research were then made available to growers and advisors through web access to the APSIM, through workshops and through several publications.
1. Building on past research to develop guidelines to support tactical and strategic decisions

a) Timing of limited water applications (see Inman-Bamber et al, 2002 and 2005 – Appendices 1 and 2, see also Appendix 3)

Methods

Two replicated experiments were established in October 2000 on ratoon crops in the Bundaberg and Childers regions of southeast Queensland. The Bundaberg trial on the farm of Mr David Lawson, was superimposed on a second ratoon crop of Q151 ratooned in July 2000. The Childers trial on the farm of Mr Graham Webb, was superimposed on a third ratoon of Q170 ratooned in August 2000. The trials were repeated in 2001/02 and 2002/03 on the subsequent ratoon crops at each site. The trials were designed in conjunction with the Bundaberg and Childers management committees of the Rural Water Use Efficiency Initiative (RWUEI). These committees selected the same four treatments for each trial. A ‘Rainfed’ treatment was not irrigated. Another treatment was given a ‘Capped’ allocation of 2 ML/ha to be scheduled by computer. Two other treatments were designed to mimic a typical allocation scenario. This entailed a starting allocation of 2 ML/ha plus additional water that may be announced by the water authorities. One of these treatments was scheduled by computer and the other was scheduled by the grower. The treatments were called ‘Plus’ and ‘Grower’ respectively. After the 2000/01 experiment the ‘Grower’ treatment at the Childers site was replaced by an ‘Unlimited’ treatment because the grower had already adopted the ‘Plus’ schedule.

For scheduling by computer, essential elements of the two experiments were captured in a configuration of the APSIM model. Soil details of a Red Kandosol were obtained from Inman-Bamber et al. (2000). Climate data pertaining to the trials were obtained from an automatic weather station (AWS) less than 1 km from the Childers site and from another AWS about 10 km from the Bundaberg site. Rainfall was measured automatically by mounting a rain gauge about 1 m above the canopy at each site. Long-term climate data were obtained from the SILO database of the Bureau of Meteorology. The Capped and Plus treatments were simulated in real time using current climate data from the AWS’s. Simulations continued up to the expected harvest date in each year using 100 years of climate records. Each treatment thus ended in 100 different ways depending on which year in the climate record was used to complete the simulation. Up to 10 irrigation strategies were used for each year in the simulation and the strategy with the highest yield was then used to identify a date for the next irrigation.

Plots were 15 m long and 12 rows wide. Irrigation was applied through trickle tape on the surface but applications were more like those from a winch system (30 to 40 mm), which is the most prevalent irrigation method in these regions. In the Childers trial, five auxanometers as described by Inman-Bamber and Spillman (2002), were installed in one replication of each treatment (20 total). These instruments were designed to measure leaf plus stalk extension continuously on an hourly basis. An EnviroSCAN (ES) system (Sentek Pty Ltd, Australia) was installed by inserting two tubes near each set of auxanometers. One tube was in the crop row and the other midway between rows, which were 1.5 m apart. Capacitance sensors were set at depths of 100, 200, 400, 600, 800 and 1000 mm. A similar system with sensors set at depths of 100, 300, 600 and 1000 mm, was installed at Bundaberg but not in time to contribute to the 2000/01 trial apart from the calibration procedure. An approximate calibration of the ES systems at Childers and Bundaberg was conducted on 19 October 2001. One gravimetric soil sample was taken to match each of the 80 sensors in both systems in terms of depth and position in the crop row or interrow. Samples were taken about 2 m from the ES tubes to avoid interfering with the ES readings. A precise calibration would require removal of soil adjacent to each sensor.
The trials at Bundaberg and Childers were sampled twice each year to determine yield, sucrose content and a number of other crop attributes using the method of Muchow, et al (1993).

**Achievements in the Bundaberg experiments**

The Grower and Plus irrigation schedules were remarkably similar for the second and third ratoon crops despite the grower's determination to follow his normal scheduling practice and to outdo WaterSense. In the fourth ratoon, the grower used all the water available by April while WaterSense saved some water for May (Figure 1).

![Irrigations applied to Grower and Plus treatments for the second (2R), third (3R) and fourth (4R) ratoons.](image)

Biomass yields were increased by irrigation in all ratoons for at least one of the samplings (Table 1). Biomass in the Plus and Grower treatments differed significantly only in the first sampling of the third ratoon. In this case the Grower biomass was greater than the Plus biomass (Table 1) which is difficult to explain given that the Plus treatment used the same amount or even more water than the Grower treatment (Appendix 2, Figure 3a). The Plus treatment received 42 mm more irrigation than the Grower treatment, which should have increased water use and yield. There was some evidence for increased water use (Appendix 2, Figure 3a) but none for increased biomass (Table 1). In the third ratoon, sucrose yield was higher in the Grower than the Plus treatment and the difference was significant for the first sampling and nearly so for the second. This was due both to higher cane yield and sucrose content in the Grower treatment. In the fourth ratoon, sucrose content was higher in the Plus treatment, significantly so in the case of the second sampling. Sucrose yield was similar in the Plus and Grower treatments in the fourth ratoon.
Table 1. Yield components in April/May (1) and at harvest, July/August (2) for four irrigation regimes applied over three ratoons, measured by sampling on 24/5/01 (1) and 25/07/01 (2) in the second ratoon; 11/4/02 (1) and 14/8/02 (2) in the third ratoon and 29/4/03 (1) and 29/7/03 (2) in the fourth ratoon. LSD=Least significant difference at P=0.05.

<table>
<thead>
<tr>
<th>Ratoon</th>
<th>Variable</th>
<th>Sample</th>
<th>Rainfed</th>
<th>Capped</th>
<th>Plus</th>
<th>Grower</th>
<th>LSD</th>
<th>P</th>
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<td>82.7</td>
<td>84.2</td>
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<td>73.6</td>
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<td>82.5</td>
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<td>10.4</td>
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<td>Irrigation (ML/ha)</td>
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<td>3.02</td>
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<td>63.5</td>
<td>69.1</td>
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<td>24.3</td>
<td>26.2</td>
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<td>7.9</td>
<td>1.9</td>
<td>0.088</td>
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<td>8.7</td>
<td>11.0</td>
<td>13.2</td>
<td>12.8</td>
<td>2.4</td>
<td>0.029</td>
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</table>

Despite the obvious difficulty in explaining the relatively low yields of the Plus treatment for the third ratoon, the grower involved was impressed with the skill of WaterSense in picking the best time to irrigate. After presenting these results to the Bundaberg RWUEI management committee the general consensus was that the optimisation procedure did a reasonably good job of forecasting when the next and subsequent irrigations should be applied. The RWUEI extension officers and committee members from both Bundaberg and Childers requested that the scheduling tool be made available for general use.

Achievements in the Childers experiments

The Childers experiment produced surprising results. Irrigation had very little effect on yield even though rainfall during both crops was low. Yield of the Rainfed treatment was low compared to the irrigated treatments in the first experiment. However the only significant treatment effect was a higher sucrose yield at sampling 3 in the Rainfed and Capped treatments compared to the other treatments (Table 2). Surprised and concerned growers involved in the trial required an explanation for the lack of response to irrigation. The untested explanation given was that lodging which was severe in the high irrigation treatment reduced growth rates and allowed the Rainfed and Capped treatments to catch up.
to some extent. In addition to this it was suggested that the roots were very deep in this soil and had access to water stored during wetter years.

Table 2. Yield components for the Childers experiments measured by sampling on 24/05/01 (1) and on 25/07/01 (2) for the 2000/2001 experiments and on 14/4/02 (3) and 14/8/02 (4) for the 2001/2002 experiments. Values with no letters in common are significantly different where p<0.05.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Sampling</th>
<th>Rainfed</th>
<th>Capped</th>
<th>Plus</th>
<th>Grower</th>
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<tr>
<td>Irrigation (ML/ha)</td>
<td>1&amp;2</td>
<td>0</td>
<td>1.81</td>
<td>3.08</td>
<td>3.33</td>
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<td>2.58</td>
<td>3.61</td>
<td>4.54</td>
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<td></td>
<td>3</td>
<td>94.5</td>
<td>90.4</td>
<td>94.5</td>
<td>87.8</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>102.3</td>
<td>92.6</td>
<td>106.7</td>
<td>100.5</td>
</tr>
<tr>
<td>Sucrose yield (t/ha)</td>
<td>1</td>
<td>8.5</td>
<td>9.1</td>
<td>10.1</td>
<td>8.1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>13.9</td>
<td>14.8</td>
<td>14.6</td>
<td>14.9</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>6.6a</td>
<td>6.5a</td>
<td>4.9b</td>
<td>4.9b</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>15.7</td>
<td>14.0</td>
<td>16.8</td>
<td>15.4</td>
</tr>
<tr>
<td>Lodging angle (°)</td>
<td>4</td>
<td>35a</td>
<td>63b</td>
<td>85c</td>
<td>88c</td>
</tr>
</tbody>
</table>

At the end of the second experiment it was decided to insert EnviroSCAN sensors to 3.0 m if possible to test the truth of this last assumption. The results of this test are given in Figure 2 showing that indeed the young ratoon in the Rainfed plots was extracting water at least as deep as 2.8 m. This was a breakthrough in RWUEI circles where the general belief was that sugarcane extracted very little water below 1.0 m (Appendix 3).

![Figure 2](image)

Figure 2. Soil water content (% volume) determined by EnviroSCAN sensors at various depths in Rainfed plots at Childers. (Means for stool and interrow positions)

b) Water production experiment to assess water allocations to each paddock (Inman-Bamber et al, 2004 – Appendix 4)

An experiment was established at Kalamia in the Burdekin to test the water production functions generated by the APSIM model which have been used extensively for decision support in irrigation and on-farm storage planning (Lisson et al, 2000). Allocations of 2, 4, 6, 8, and 10 ML/ha were scheduled by
the procedure described above assuming 40 mm would be applied per irrigation as in a winch irrigation system. Thus each allocation was used in the best possible way for a winch type system since the results of this research were aimed at best use of limited water even though the work was conducted in the Burdekin. A trickle system was actually used to ensure that applications were precise. A ‘Full’ treatment was also included. This was irrigated 2 or 3 times each week to replenish water lost through evapotranspiration which was determined by APSIM until 70% canopy closure and then as 1.25 x FAO daily reference evaporation. Plots were 25 m long and 9 rows wide. There were three replications. Yield sampling was conducted on 11 December 2001, 27 February and 3 June 2002, which was just before harvesting. The experiment was repeated on the first ratoon crop in 2002/03. Irrigation treatments started 12 July 2002. Yield sampling as described above was done on 17 February and 11 August 2003 and the crop was harvested on 21 August, 2003.

Achievements – Plant crop

Rainfall during the 15 month growth period was 728 mm which is below average (1188 mm) for this period. Allocations up to 8 ML/ha were fully utilized but the 10 ML/ha allocation could not be completed before starting drying off prior to harvesting in early June (Table 3). The Full treatment received 52 mm more water than the 10 ML treatment because there was no set soil water deficit when irrigation could be applied and the only constraint was the need for drying off before harvesting.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>2 ML/ha</th>
<th>4 ML/ha</th>
<th>6 ML/ha</th>
<th>8 ML/ha</th>
<th>10 ML/ha</th>
<th>Full</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation applied (mm)</td>
<td>200.0</td>
<td>400.6</td>
<td>601.0</td>
<td>800.3</td>
<td>941.5</td>
<td>993.1</td>
</tr>
<tr>
<td>Last date of irrigation</td>
<td>07-Dec-01</td>
<td>25-Jan-02</td>
<td>27-Mar-02</td>
<td>24-Apr-02</td>
<td>10-May-02</td>
<td>20-May-02</td>
</tr>
</tbody>
</table>

Well irrigated plots started to lodge in February during a rain storm which delivered 378 mm over three days. Lodging was assessed only in June just before harvesting. Increased irrigation resulted in increased lodging such that with 8 ML, 10 ML and Full treatments, all stalks at the base were level with the ground at harvest (Appendix 4, Figure 1a). Lodging disrupted the canopy of the high irrigation treatments during an important period for cane and sucrose yield accumulation. Cane yield was reduced in the low allocation treatments at both December and February samplings but in the June sampling, only the 2 ML treatment had a reduced yield. All other treatments yielded about 140 t/ha at harvest. Sucrose content was not affected significantly by treatment (Appendix 4, Figure 1g). Sucrose yield in February and June was similar in all treatments apart from the lowest allocation (Appendix 4, Figure 1h).

Achievements - First ratoon crop

Rainfall during the 13 month growth period was 557 mm which is very low compared to the mean annual rainfall (956 mm). All allocations were fully utilized, some as early as December. The Full irrigation treatment received only 79 mm more than the 10 ML allocation treatment but this allowed irrigation to meet crop demand for about six weeks after the 10 ML had terminated (Table 4).
Two storms in February delivered 162 and 156 mm over 5 and 6 days respectively. A lodging assessment (and sampling) was done before the second storm and at this stage the Full treatment was already 50% lodged. Lodging increased linearly with allocations up to 10 ML/ha and then increased disproportionately with a further 78 mm (0.78 ML/ha) water received by the Full treatment (Appendix 4, Figure 2a). Severe lodging in the Full treatment was probably due to the regular irrigation and consequent reduced soil strength as well as the relatively large crop that had developed prior to the storms in February.

The number of stalks lost between February and August was substantial (Appendix 4, Figure 2b). The loss was 3 to 4 times greater in the 10 ML and Full treatments than in the 2 ML and 4 ML treatments.

Total aboveground biomass increased with irrigation up to 8 ML/ha in February but differences were small and non significant in August (Appendix 4, Figure 2e). There was no gain in biomass in the Full treatment over this time while the gain in the 2 ML treatment was more than double even though irrigation for this treatment ran out in December 2002 (Table 4). The poor growth in well irrigated treatments was to a large extent due to stalk death since the biomass of individual stalks increased by about 200 to 300 g in all treatments (Appendix 4, Figure 2i).

Cane yield increased with irrigation in February but differences in August were not significant (Appendix 4, Figure 2f). The trend towards higher yields in the 6 and 8 ML treatments in August could be due to the combined effect of water stress at lower allocations and the effect of lodging at higher allocations. Similar comments could be made for sucrose yield (Appendix 4, Figure 2h). The increase in sucrose yield from February to August was 400% in the 2 ML treatment and only 50% in the Full treatment.

These results have important implications for decisions about investment in irrigation infrastructure including on-farm dams. Software tools such as Dam Ea$y (Lisson et al. 2000) do not consider limitations to yield imposed by lodging. Estimates of yield response and profit from irrigation may be too high when considering increased allocations resulting from storages particularly in the higher range of allocations. The phenomenon of lodging and consequent yield loss due to irrigation increases the risk of investments in supplementary irrigation in a way that may not have been considered before.

c) Carry-over effect of water stress (extending ratoon life) – Appendices 5 and 6

A carry-over (residual) water stress experiment was conducted on each of the 1st and 2nd ratoon crops of the water production experiment described above.

Methods

In the first water production experiment (1b), the 2ML treatment was irrigated last in December 2001. The trial was harvested in on 2 July 2002 (Table 1). With the low rainfall experienced in the ‘wet’ season, the crop ratooning after harvesting could be expected to be adversely affected by these very
dry conditions if a residual effect of water stress applies to the subsequent ratoon which is what most growers expect. Conversely the Full treatment was irrigated regularly until 20 May 2002. The ratoon crop would benefit from this more favourable treatment if a residual (carry over) effect from one crop to the next applies.

Trickle tape was replaced soon after harvesting apart from a section (5 m x 4 rows) of each plot in which irrigation was to be excluded until after the first irrigation. Shoots were counted in a 3.0 m length of crop row over two drills in each of these sub-plots as well as in sections that were irrigated shortly after harvest according to the planned treatments for the second experiment. Shoots were counted on three occasions (1 and 23 August and 24 September).

Treatments applied to the second water production experiment resulted in a wide range of periods without irrigation prior to harvesting in August 2003 (Table 2). The 2ML/ha treatment was not irrigated for 8 months before harvest and the Unlimited treatment was dried down only for 2 months. Rainfall for the crop was very low (557 mm).

The 2nd ratoon was irrigated uniformly starting soon after harvesting. The trial was sampled in February 2004 when the crop was five months old.

**Achievements**

Analysis of variance of the shoot counts indicated that irrigation applied to the plant crop had no significant effect on shoot population of the first ratoon regardless of whether irrigation was applied after harvesting the plant crop or not. These results suggest that there is little residual effect of drying off conditions prior to harvest on the vigour of the subsequent ratoon. If this effect was important, one would have expected a much larger response to the wide range of drying off treatments.

Likewise, irrigation treatments applied to the first ratoon crop had no significant effect on stalk population, cane yield or biomass of the second ratoon crop. The trend was for reduced stalk population, cane yield and biomass with increased irrigation (Figure 3). A regression of cane yield on allocation treatments (2, 4, 6, 8 and 10 ML) was just significant (p=0.05).

![Figure 3. Total fresh weight (●) and stalk count (X) per 15m² of sample area for samples taken on 17 February 2004 in a second ratoon following a first ratoon experiment with six irrigation treatments.](image-url)
It was expected that dry conditions prior to harvest of the first ratoon would limit stalk numbers and yield of the second ratoon. This was not evident in the sampling data for February (Figure 3) which indicated that dry conditions favoured stalk population and yield, if anything.

At harvest of the first ratoon (August 2003), stalk population was lower for high irrigation treatments (>1000 mm) than for lower treatments. Stalk counts when the 1st ratoon was harvested (August 2003) were significantly correlated with stalk counts of the 2nd ratoon in February 2004 on a treatment mean basis but not on a plot by plot basis (Appendix 5).

The mechanism proposed for the carry over effect is through stalk population and through survival of stools after lodging. A uniformity rating of each plot made on 27 October 2003 was correlated with a lodging rating made when the first ratoon was harvested. Uniformity was rated low when stool tipping was observed and when stool regrowth was gappy or non uniform.

d) Making use of water upflow from water tables (Appendices 7, 8 and 9)

Simulating upflow from water tables using the SOILWAT2 module in APSIM

Results from trickle irrigation experiments at Fairymead (Bundaberg Sugar) indicated that the water table which was often at a depth of 1 m or less, contributed substantially to crop water requirement. A detailed soil physical model (SWIM) has been parameterized in order to account for up flow of water to roots above a water table (Sweeney et al., 2002). The use of SWIM requires considerable knowledge of soil physical properties. We attempted using the SOILWAT2 module in APSIM to simulate water up flow from the following much simpler algorithms.

\[
\text{Diffusivity} = a + \exp(b \cdot \theta_{av})
\]

Where \(a\) and \(b\) are soil specific constants and \(\theta_{av}\) is the average available soil water content of the saturated layer (water table) and the layer above the water table.

\[
\text{Upflow} = \frac{\text{diffusivity} \cdot (\theta_{sat} - \theta)}{z}
\]

Where \(\theta_{sat}\) is the water content of the saturated layer, \(\theta\) is the water content of the layer above the saturated layer and \(z\) is the depth of this layer.

The above steps were repeated for all layers above the water table so that roots which may be some distance from the water table can access the up flow.

This procedure was used to assess the contribution of a water table to crop yield in a dry-down experiment at Kalamia (Inman-Bamber, 2004, CTA038). In this experiment some plots were irrigated regularly after the wet season in 1999/2000 (wet) and others were not irrigated at all (dry). The height of the water table near this experiment was measured by placing a piezometer (pressure transducer) in a perforated tube at a known depth below the soil surface (Appendix 8).

Simulations were carried out with and without a water table at 1.5 m. Roots were allowed to ‘grow’ to within 600 mm of the water table.
The following steps were required to simulate a watertable using SOILWAT2.

1) The following command was provided in the manager parameter file so that 5mm water could be added to layer 8 every day.

   Soilwat2 set dlt_sw_dep = 0 0 0 0 0 0 0 5

2) SWCON for layer 8 was set to zero so that soil in this layer would remain saturated apart from when upward flow and uptake by roots occurred.

Long term simulations were also performed to assess the effect of the presence of a water table on timing for the best use of limited water using the Fairymead climate record obtained from the 'Patched point' data set of the SILO database base from BOM. Allocations of 0, 1, 2, 3 and 4 ML/ha were applied to a September ratoon crop in the simulations. A water table at 1.0 m in a Red Ferrosol was simulated.

Achievements

Kalamia (Appendix 8): The yield achieved in the unirrigated treatment of the Kalamia experiment was simulated more accurately when upflow from the water table was included in the simulation than when no water table was included. Inclusion of the water contribution from the water table increased the yield by about 10% in the dry treatment and <1 % in the wet treatment (Appendix 8).

Fairymead (Appendix 9): A water table had a larger effect on the best time to use limited water when allocations were low compared to when allocations were high, as may be expected (Figure 4). With low allocations (1 and 2 ML/ha) and no water table, most of the water was required for regeneration of the ratoon crop. In the presence of a water table, low allocations were more useful during the high evaporative demand period, December to February. With high allocations (3 and 4 ML/ha) and a water table, growers could afford to use more of the allocation in February and March and less in November and December compared to a situation where no water table was present. Lodging was not prevalent to any great extent in the simulations and did not influence the best time to use limited water.
To complete the picture it is interesting to note the effect of water table on response to irrigation (Figure 5). The water table contributed to an additional yield of about 40 t/ha at low allocations and about 30 t/ha at high allocations.
e) Withholding irrigation to reduce risks of waterlogging (Appendix 10)

Methods

Simulations were conducted with APSIM-Sugarcane to assess the risk of germination failure from waterlogging. The following settings and assumptions were made in the simulations:

1) Establishment was deemed to be complete when leaf area index exceeded 0.05.
2) Planting was simulated for the first day of each month excluding the period May to August when planting is not normally carried out.
3) Soil water at planting was set at 50% of total plant available water capacity (PAWC).
4) Waterlogging was deemed to have started when soil water content in the top 40 cm soil was at or above the drained upper limit.
5) Germination was deemed to have failed if the soil was waterlogged for more than four days.
6) Simulations were conducted with and without irrigation in the establishment period.
7) For the irrigation treatment, 25 mm was applied if the soil water deficit was greater than 30 mm provided 14 days had lapsed since the last irrigation.

Achievements

Irrigation required for germinating the crop generally added very little to the risk of waterlogging (Figure 6) and the main threat was from rainfall. This was particularly evident in the high rainfall regions north of Townsville as may be expected (Appendix 10). These simulations assume some impediment to drainage such as a perched water table or some impervious layer. The simulations do not take into account water flowing onto the paddock from higher ground. Such on flow would increase the risks shown in Appendix 10. The point from this simulation work is that the small quantity of irrigation required for germination (25 mm in the simulations) does not increase the risk of waterlogging in any region to any great extent. High rainfall after germination poses the greater risk by far. The results of these simulations can be used as a guide for when to plant to reduce risk of waterlogging in paddocks with poor drainage.

Figure 6. Probability of germination failure from waterlogging, with and without irrigating 25 mm after planting.
2. Further enhancing sugarcane systems modelling capability

APSIM Simulation capability was improved in three main areas, lodging, soil water extraction and contribution from shallow water tables. Methods and results for the latter were described above.

a) Introducing lodging algorithms to improve modelling of water production curves

The APSIM-Sugarcane model was set up to simulate the two water production experiments described in (1b) as well as an experiment conducted at Bambaroo during SRDC project CSE018. Characteristics of a Red Dermosol (Inman-Bamber et al, 2000) were used for simulation of the Kalamia experiments (1 and 2). The soil parameters for the Bambaroo experiment were given by Inman-Bamber et al, (1999). Automatic weather stations located within 1 km from each experiment provided daily rainfall, temperature and radiation data needed for simulation of the experiments. Long-term simulations were done for the Burdekin to assess climatic and crop conditions for lodging. The Bureau of Meteorology’s SILO database for Ayr was used for this.

Simulation of the Kalamia experiments (1b) with APSIM-Sugarcane indicated that responses to irrigation in December and February were ‘normal’ in terms of the physiology of sugarcane as captured in the model (Figure 7a, 7c). However, when the crop was harvested (June 2002 and August 2003), high allocation treatments yielded far less than was expected by the simulation. The lack of response above 4 ML/ha was explained to some extent (Figure 7b, 7d) by invoking the following lodging rules in the model.

1) Lodge when more than 15 t/ha biomass has accumulated
   a. if it rains more than 600 mm in one storm
2) Lodge when more than 30 t/ha biomass has accumulated
   a. if it rains more than 300 mm in one storm
   b. and antecedent soil water content of the surface soil (to 400 mm) is more than 30% of the maximum.
3) Lodge when more than 40 t/ha biomass has accumulated
   a. if it rains more than 150 mm in one storm
   b. and antecedent soil water content is more than 50 % of the maximum.
4) Reduce photosynthesis and water use by 30% after lodging

A storm was considered to be over after three rain free days. These rules also accounted for the observations of the Bambaroo experiment where the additional irrigation of the High treatment caused a significant yield reduction (Figure 4, Appendix 4).
Figure 7. Measured (symbols) and simulated (lines) water production curves for Experiment 1 (a, b) and Experiment 2 (c,d) with no lodging simulated (a, c) and with lodging simulated (b,d). Measurements and simulations are for samplings on 11 Dec 01 (○), 27 Feb 02 (△) and 3 June 02 (▲) in the case of Experiment 1 and for 17 Feb 03 (○) and 11 August 03 (△) in the case of Experiment 2.

b) Soil water extraction (Appendix 11)

The ‘Manager’ module of the APSIM model v 1.6 was configured to mimic all field operations pertaining to the three experiments including planting, fertiliser application, hilling-up, irrigation, burning and harvesting as described by Robertson et al (1999). Parameters for the “Sugar” module were those supplied with the software (defaults). Parameters for the “Soilwat2” module were measured or adjusted to represent the soil of the experimental site. The drainage coefficient was set to 0.5 and 0.9 for the clay and sand horizons respectively. The maximum fraction of available soil water that can be extracted in a day ($k_l$) was determined by fitting soil water content (SWC) to an exponential decay function of time (eq 1)

$$SWC = LL + (DUL - LL) \exp(-k_l(t-t_0))$$  (1)

Where $t-t_0$ is the duration (days) of the exponential decay, which starts in a layer at time $t_0$.

Equation 1 was fitted to SWC measured at six depth intervals (3 x 200 mm, 3 x 300 mm) resulting in $k_l$ values of 0.100, 0.063, 0.049, 0.055, 0.064 and 0.086 for successive soil depths. Simulated available water (AW) in the soil profile was mostly within one standard error of mean measured AW (Figure 8). Default $k_l$ supplied with APSIM was about 60% greater than the measured values which have introduced more realism into subsequent APSIM simulations.
Figure 8. Measured (symbols) and simulated (line) available water (AW) during a plant and a ratoon crop of Q96 which were denied irrigation during mid-season. X-axis is thickened to show stress periods (solid) and a drying off period (broken). Bars show mean ± one standard error. Arrows show planting and ratoon dates respectively.

3. Customizing tools for industry

The RWUEI extension officers and committee members from both Bundaberg and Childers requested that the scheduling tool developed for optimum timing of limited water (1a), be made available for general use. The development of the web tool was fully described by Inman-Bamber et al (2005, Appendix 2). The web-tool called 'WaterSense' has been developed for growers in the Bundaberg and Childers regions initially. The tool should be viewed as the beginning of a process to make computer intensive technology available to cane growers in general. Web pages and output are likely to improve as we work with these groups to deliver information that is reliable and easy to use. However, the essential processes of obtaining up-to-date weather data, entry of paddock details, simulating crop growth, optimising irrigation strategies and delivering a plan or schedule is likely to remain as it is now.

Computers at CSIRO Davies lab in Townsville store historic climatic data obtained from the Bureau of Meteorology’s SILO database. These computers down-load current climate data every day from four AWSs operating in the Bundaberg/Childers region. One computer contacts a CSIRO server in Canberra at 10 min intervals to see if anyone has requested a job. The Canberra server supports the web pages (Figure 9) which are used to enter details about the paddock (Figure 9b), to check or alter rainfall and to initiate the necessary APSIM simulations which take about 40 min for each paddock. The subsequent optimisation is completed rapidly and an email is generated (Figure 9d) and sent immediately to the user.
Two figures are attached to the email (not shown). One figure shows best irrigation dates for all years in the simulation in the form of a cumulative distribution functions (CDF) and the other the best usage of water in each month by irrigation number. Certainty about the best times to use limited water decreases the further into the future the prediction is made. As irrigation events are recorded and the proportion of actual to historic weather increases, so the best time to apply the next irrigation becomes more certain. Also, the probability of predicting the correct irrigation date is much greater for irrigations in the near rather than in the distant future (Figure 10). While information about irrigations far into the future may be vague, the CDFs do indicate by when the allocations should be used. In the example in Figure 10, there is an 80% chance that the whole allocation of 4 ML/ha should be used by the end of March 2005 (i.e., in 80% of the years). Hopefully, this type of information will encourage growers to use all their allocated water every year.

Figure 9. Thumbnail images of Watersense's web pages and email response.

Figure 10. An example of information generated by WaterSense for a paddock planted in March 2004 (a), to be harvested in July 2005 (c), allocated 4 ML/ha water to be applied in 8 irrigations of 50 mm each at 85% efficiency, on a Forest Grey soil in Bundaberg. The forecast was updated on 10 November 2004 (b). The first irrigation was applied on 15 July 2004 and second was due
immediately after the update. Although the eight CDF lines (labelled 1 to 8) are shown here, the current version of WaterSense only shows the CDF line for the next irrigation.

As far as is known this type of irrigation scheduling optimisation technique that was developed and tested experimentally for sugarcane has not been reported before, certainly not in sugarcane. WaterSense allows assessment of the value of increased allocation taking into account the risk of not being able to use all of it in wet years. This risk needs to be assessed when gaining access to water either through investing in infrastructure or simply through purchasing allocation on a seasonal or longer term basis. WaterSense can be used not only to plan water use through the year but also to assess the response to increased allocation. However, the main purpose for its development was to assist in planning of seasonal irrigation scheduling.

A process is now underway to explain WaterSense to interested cane growers and particularly to highlight the probabilistic nature of the data (Figure 10). Operation and presentation will be changed after consultation in order to improve the usefulness and accuracy of this tool.

4. Work with extension officers in applying these tools in an action research context with industry.

The field research described in 1a, 1b and 1c was essentially conducted for and under the close scrutiny of the RWUEI committees in Bundaberg and Childers. Results were reported back to these committees at least annually. At these meetings plans for future work were discussed and accepted by the committees.

The development and field testing of WaterSense was conducted under the guidance of the RWUEI adoption program and by RWUEI extension officers Craig Baillie (Bundaberg) and John Wilcox (Isis) in particular. WaterSense was the entry level tool for further development in a concurrent SRDC project CSE009 ‘Moving from case studies to whole of industry: Implementing methods for wider industry adoption’. A state-wide workshop was arranged jointly by Mr Tony Linedale and Geoff Inman-Bamber in March 2004. Follow up workshops were arranged in Brandon (March 2006) and in Mackay (April 2006). Regular meetings under the CSE009 project were held in Bundaberg with Tony Linedale and Maurie Haines (BSES) and at Sarina (Rob Sluggett, BSES) to further develop the technology and to teach growers how it all worked.

a) Sugar industry irrigation workshop, Arranged by BSES and CSIRO, sponsored by SRDC and CRC IF, Illawong Resort, Mackay, March 3, 4: 2004

This workshop provided an opportunity for all those involved in irrigation R&D to share current knowledge and experiences and to plan for future R&D to influence the sugar industry with this knowledge. A total of 33 presentations were made to about 40 delegates over two days. Slides of the presentations and points of discussion of groups of these presentations are provided in Appendix 12. These points were gathered together in the last session and actions were then highlighted for various delegates to undertake.
Some of the main points of general discussion were as follows.

*Best management practice* (BMP) needs to consider regional variation and that BMP is not static but is a continuous improvement process. BMP needs to be widened to encompass triple bottom line accounting. BMP issues need to be identified for the region concerned and leadership from the cane growing community needs to drive BMP to resolve these issues. We need to establish pathways for increasing adoption and technical support for this process can come through partnerships between R&D agencies and communities.

Irrigation is part of the farming system including soil management, weed control and implementation of new crop rotations and crop configurations. Irrigation extension efforts must be linked across the industry particularly in relation to the promotion of new farming systems. Resources need to be shared across R&D programs to do this. This is an issue of reviewing BMP standards. Who is responsible for this?

*Performance reporting* based on measuring and monitoring after benchmarking is required. This implies continuous improvement in irrigation practice. Advisers (both public and private) and irrigators need to develop the benchmark practice. Researchers need to develop the tools for measuring and monitoring and farmers, advisors and researchers need to put these tools in place.

*Coordinating and sharing information* needs to be improved both within and outside sugar industry. Funds ($30,000) should be sought to run an annual forum like this one. Such funds could be requested from BSES, SRDC and QDNR&M. The sugar industry needs to be represented in the CRC IF and it needs to be actively involved in the Northern zone, promoting the aims of the CRC IF.

*Interpretation of Research Information to Growers* should result in conversion of research outputs into practice change. Research outputs can be captured on CD as in the RWUE CD produced by Steve Raine. This information should be updated and promoted during RWUE2. Researchers need to ensure that their research is linked to end users. Researchers need to understand current irrigation practice. Improved links between researchers, extension and farmers will ensure that information flows both ways. End user information needs to be acknowledged and valued by researchers. For this, researchers need to develop skills in communication and interaction with end users and both parties need to understand each other’s aspirations, knowledge and needs.

Other more specific issues were discussed under the questions of *what, how and who* (Appendix 12).
b) Workshop at BSES Brandon, 14 March 2006, 9.00 am to 12.30 pm

The aim of this workshop was to discuss the science behind the WaterBalance web scheduling system which is being developed under funding from other projects, CSE007 and CSE009. The work conducted in CSE001 was mentioned but did not have much relevance to a region with effectively unlimited water.

c) Irrigation workshop held at BSES Mackay 5/5/06 (9am to 3pm): Implications of recent SRDC funded irrigation R&D (Appendix 13).

Present: Dollat (RWUE); Che Murray (BSES); Joe Muscat (BSES, Grower); George Jackson (BSES); Gerry (BSES); Phil (MAPS); Burn Ashburner (MAPS); Rob Sluggett (BSES); Brad Hussey (BSES); Steve Attard and Geoff Bamber (CSIRO)

The meeting was started by Rob Cocco (BSES Area manager, Mackay) who left early. The general response was very positive and everyone expressed an appreciation for the effort we took to come to Mackay to present the results of our research. Eoin Wallace (BSES, CEO) also thanked us for this effort. The agenda included science and application of WaterSense and WaterBalance irrigation management tools, the future of these services/tools and opportunities for BSES to implement these and other tools derived from SRDC funded irrigation research.

We noted requests for inclusion in the new version of WaterSense such as:

- Grouping of paddocks by, rain gauge (as is now), pump, farm, irrigator and valve
- Presenting rainfall compared to average rainfall to help explain why WaterSense forecasts irrigation on certain dates? We suggested monthly rainfall would be appropriate, not daily rainfall.
- All agreed that simplicity should be favoured over information overload.
- Capability to assess the value of additional irrigations

Future actions and projects

Dameasy: There was a lot of discussion about Dameasy type capability and everyone agreed that this was urgently required for Mackay. We explained that many groups (even in other industries) acknowledged this but no one has committed funds to developing this capacity for the issue they regard as so important.

There was strong support for some targeted workshops to share the material discussed at this workshop with people who could help to implement it (WaterSense, WP, Dameasy type technologies) in Mackay with the ultimate aim of ‘getting more’ and ‘using it better’, to coin Brad Hussey’s terms.

OUTPUTS

Understanding of crop physiology

The project has produced new knowledge concerning crop physiology and crop modelling. Areas of sugarcane physiology that have been refined as a result of the project include responses of leaf and stalk extension to water stress, depth of root water extraction by sugarcane (up to 2.8 m), root water extraction coefficients, factors (soil, climate and crop) that favour lodging. The APSIM model has been improved due to the investment in this project. For example, the ability of APSIM to simulate crop growth under high water stress and rainfed conditions has been improved. APSIM can now simulate lodging where it previously had to be programmed by the user to lodge the crop. APSIM can now simulate water contributions from a water table more simply than before. The project has resulted in six publications in the national literature and two in the international literature. A paper by Inman-Bamber, N.G., and Smith,
M.D. (2005), (Water relations in sugarcane and response to water deficits. Field Crops Res. 92, 185-202) was in the top 10 most downloaded FCR articles in December quarter of 2005.

WaterSense Irrigation Scheduling Tool

The experiments in Bundaberg and Childers showed that a computerised scheduling technique called WaterSense tended to do as well as or somewhat better than what good growers can achieve particularly in unusual seasons. The results support the use of WaterSense for planning ahead for the water year. One of the main implications of this research is that it helps growers to assess the value of water allocations used earlier than current practice since in many situations allocations were not fully used by the end of the water year. Growers tend to keep water in reserve in case of severe dry periods. This research assesses and balances the risks of water stress throughout the crop growth cycle such that growers can benefit from large responses to early irrigation without undue risk of running out of water.

WaterSense was made available on the web and allows growers to access four automatic weather stations in the Childers/Bundaberg region and set up simulations to optimise decisions regarding use of available irrigation water. The program is being tested and refined with the assistance of growers and industry extension personnel in Bundaberg and Sarina regions. Early prototypes have been presented at workshops throughout the project.

Water Production Functions

Marginal responses to irrigation under different circumstances (region, soil type, ratoon date, dry – wet years) have been quantified and provided as Pivot tables in an Excel program. These functions have been used extensively by RWUEI extension staff to encourage growers to use all their allocated water and by economists to assess the value of recycled water in Mackay. The water production functions do not include research conducted later in the project which demonstrated the affect of lodging on marginal response to increased allocation. The latter results may have important implications for investment in water infrastructure including on-farm storage. Current estimates of yield response and hence profit from irrigation may be too high when considering increased investments in or allocations from storages. The finding that the lack of response to extra water due to lodging increases the downside risks in investment in supplementary irrigation.

Water tables

Modelling capability has also been enhanced by this project to take into account the influence of water tables on the optimum use of limited irrigation water. Also simulation of the effect of waterlogging during germination indicated that the risk from irrigation was small. However, the waterlogging risk from rainfall alone in some regions is very high in certain months and this information can be used by growers to reduce risk.

Lodging

While irrigation can exacerbate lodging, a major output of the project was that lodging of sugarcane can limit the response to irrigation. It was found that sugar yield is limited by lodging with no added sugar yield response above 4 ML per ha at the Burdekin trial site. This suggests that in these circumstances water can be saved with associated benefits of less labour use and lowered offsite impacts.
Impact of irrigation on ratoon health

Many growers believed that dry conditions prior to harvest reduced the vigour of the subsequent ratoon. The experiments in the Burdekin did not support this hypothesis as yield of the new ratoon was not affected by drying off between 2 to 7 months in a dry year. If anything, the dry conditions that developed before harvest from reduced irrigation could have benefited the crop provided the young ratoons were irrigated soon after harvesting. It should be noted that these experiments were carried out where the seasonal conditions did not cause stalk death in the previous crop and impacts may be different in that situation.

ENVIRONMENTAL AND SOCIAL IMPACTS

The main benefit of this work is to improve water use efficiency and farm profits. However in doing this growers will be complying with community and legislative requirements to use limited water most efficiently. For example, use of WaterSense in seasonal water planning will be suitable proof of implementation of best practice for Land and Water Management Plans now required by DNR&M for proposals to divert water in various ways. The research has provided a scientific platform for a debate on the opening and closing dates of the water year which is a source of anxiety in many communities with limited water. Hopefully this debate will guide water providers and users to arrive at the best arrangement in the interests of water use efficiency. The current arrangements encourage growers to irrigate simply to use water they have already paid for even if it has no benefit to the crop. As pointed out under ‘recommendations’, the web-based scheduling service will provide the necessary records of water use, runoff and drainage that will eventually be required by law and possibly by markets and will allow users to claim best practice based on the best science.

EXPECTED OUTCOMES

Taken from a report by Dr Peter Chudleigh of Agtrans Research

The benefits of this project are assumed to apply to irrigators in the sugarcane producing regions of Maryborough, Childers, Bundaberg, Sarina, Mackay and Proserpine. The principal benefit assumed is an increased average cane yield from real time scheduling aids that will generally advocate using water earlier in the season than later or not at all. As is often the case at present. It is assumed that improved timing and full use of limited allocations could give a further 10 tonnes of cane per ha.

Adoption

It is assumed that in the Bundaberg and Isis areas some 95% of growers have access to some water and that the improved scheduling aids will be available and relevant to them. For the second area (Maryborough, Sarina, Mackay, and Proserpine) the percentage assumed is 80%.

Despite the magnitude of the potential benefits, it is believed that a number of factors will limit the adoption of the improvement including:
- the risk-averse nature of many growers
- lack of water to be allocated in some regions in some years
- the labour demanding nature of irrigation when other competing activities also require labour early in the growing season (e.g. spraying, fertilising).

On the other hand, at least in the Bundaberg region, the number of cane farms is contracting which should make the encouragement of adoption of change easier.
Attribution of irrigation practice change to CSE001 is another factor to be considered in association with adoption as similar principles had been established earlier through other projects. Bundaberg Sugar for example has more or less changed practices to earlier irrigation (although constrained by labour shortages). While these changes had been made before CSE001 findings were available, the findings did confirm the practice change (Mike Smith, pers. comm., December 2005).

Notwithstanding the contribution to adoption of irrigation practice, change by CSE009, CSE001 will be completed in early 2006 with only a start made in direct extension effort of the findings and end user involvement in the final decision aid that is delivered. The following assumptions on adoption are therefore made without considering any input into further development of the decision aid and any further investment into its extension.

A maximum of 2% of the area with access to water in the Bundaberg and Isis areas is assumed to adopt whatever guidance products emanate from CSE009 and CSE001. This maximum is assumed to be reached in the year 2016/2017. A maximum of 1% of the area with access to water is assumed to adopt in other relevant areas. A linear rate of adoption is assumed in both cases, commencing in the 2007/08 year for 10 years. These adoption rates are assumed to be the actual difference made by CSE001 and CSE009 alone so no attribution factor has been applied.

Summary of Assumptions

Table 5. Summary of assumptions made in the quantitative analysis.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Assumption</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase in cane yield</td>
<td>10 t cane per ha</td>
<td>Discussions with Geoff Inman-Bamber</td>
</tr>
<tr>
<td>Areas to which yield increase could apply</td>
<td>(i) Bundaberg and Isis (ii) Maryborough, Sarina, Mackay and Proserpine</td>
<td>Discussions with Geoff Inman Bamber</td>
</tr>
<tr>
<td>Total area of cane in</td>
<td>Area (i) 50,000 ha Area (ii) 149,000 ha</td>
<td>Hildebrand (2002)</td>
</tr>
<tr>
<td>Proportion of area to which potential increase could apply</td>
<td>Area (i) 95% has access to water Area (ii) 80% has access to water</td>
<td>Discussions with Geoff Inman Bamber and others</td>
</tr>
<tr>
<td>Maximum adoption</td>
<td>Area (i) 2% of area Area (ii) 1% of area</td>
<td>Agtrans, after discussions with Craig Baillie, Tony Linedale, Geoff Inman-Bamber, and Mike Smith</td>
</tr>
<tr>
<td>Year of first adoption</td>
<td>2007/08</td>
<td>Agtrans</td>
</tr>
<tr>
<td>Year of maximum adoption</td>
<td>2016/17</td>
<td>Agtrans</td>
</tr>
<tr>
<td>Sugar Price</td>
<td>$285 per tonne sugar</td>
<td>Average for the five years to 2004/05 (Australian Commodity Statistics)</td>
</tr>
<tr>
<td>Cost of harvesting additional cane</td>
<td>$6 per tonne of cane</td>
<td>Agtrans</td>
</tr>
<tr>
<td>Cost of transporting additional cane</td>
<td>$2 per tonne of cane</td>
<td>Agtrans</td>
</tr>
<tr>
<td>Cost of factory processing additional cane</td>
<td>$90 per tonne of sugar</td>
<td>Agtrans</td>
</tr>
<tr>
<td>Cost of transporting additional sugar</td>
<td>$2 per tonne of sugar</td>
<td>Agtrans</td>
</tr>
</tbody>
</table>
Results

All costs and benefits were expressed in 2004/05 dollar terms using the CPI. All costs and benefits were discounted to 2004/05 using discount rates of 5% and 10%. All analyses ran for 30 years from the first year of investment (2000/01) to the final year of benefits assumed (2029/30).

The investment criteria were all positive as reported in Table 6.

Table 6: Investment Criteria for Total Investment and Total Benefits

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Discount rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5%</td>
</tr>
<tr>
<td>Present value of benefits (m$)</td>
<td>3.58</td>
</tr>
<tr>
<td>Present value of costs (m$)</td>
<td>1.89</td>
</tr>
<tr>
<td>Net present value (m$)</td>
<td>1.69</td>
</tr>
<tr>
<td>Benefit cost ratio</td>
<td>1.9 to 1</td>
</tr>
<tr>
<td>Internal rate of return (%)</td>
<td>9.4</td>
</tr>
</tbody>
</table>

It is apparent that while the productivity gain is quite large, the estimate of benefits is considerably reduced by the low adoption rate assumed.

Sensitivity Analyses

Sensitivity analyses were carried out on a range of variables and results are reported in Tables 6, 7, and 8. All sensitivity analyses were performed using a 5% discount rate. All other parameters were held at their base values.

Table 7 shows that halving or doubling the average yield improvement provides a significant impact on the investment criteria.

Table 7. Sensitivity to Cane Yield Improvement

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Level of cane yield improvement (tonnes of cane per ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Present value of benefits (m$)</td>
<td>1.79</td>
</tr>
<tr>
<td>Present value of costs (m$)</td>
<td>1.89</td>
</tr>
<tr>
<td>Net present value (m$)</td>
<td>-0.10</td>
</tr>
<tr>
<td>Benefit cost ratio</td>
<td>0.95 to 1</td>
</tr>
</tbody>
</table>

Table 8 shows that the sensitivity of investment criteria to the level of maximum adoption. Obtaining a maximum adoption rate of 20% for Area 1 and 10% for Area 2 could deliver very high levels of benefits.
Table 8. Sensitivity to Maximum Adoption Level

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Maximum Adoption Level (% of those who have access to water)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2% Area 1 and 1% Area 2 (Base)</td>
</tr>
<tr>
<td>Present value of benefits (m$)</td>
<td>3.58</td>
</tr>
<tr>
<td>Adoption Rate x 2</td>
<td>7.16</td>
</tr>
<tr>
<td>Adoption Rate x10</td>
<td>35.8</td>
</tr>
<tr>
<td>Present value of costs (m$)</td>
<td>1.89</td>
</tr>
<tr>
<td>Net present value (m$)</td>
<td>1.69</td>
</tr>
<tr>
<td>Benefit cost ratio</td>
<td>1.9 to 1</td>
</tr>
</tbody>
</table>

Table 9 shows that the investment criteria are quite sensitive to the sugar price. The break even price for sugar for the project to have returned a 5% rate of return was $222 per tonne.

Table 9. Sensitivity to Sugar Price

<table>
<thead>
<tr>
<th>Level of sugar price ($/t)</th>
<th>Criterion</th>
<th>235</th>
<th>285 (Base)</th>
<th>335</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present value of benefits (m$)</td>
<td>2.23</td>
<td>3.58</td>
<td>4.92</td>
<td></td>
</tr>
<tr>
<td>Present value of costs (m$)</td>
<td>1.89</td>
<td>1.89</td>
<td>1.89</td>
<td></td>
</tr>
<tr>
<td>Net present value (m$)</td>
<td>0.35</td>
<td>1.69</td>
<td>3.04</td>
<td></td>
</tr>
<tr>
<td>Benefit cost ratio</td>
<td>1.2 to 1</td>
<td>1.9 to 1</td>
<td>2.6 to 1</td>
<td></td>
</tr>
</tbody>
</table>

Conclusions

CSE001 builds on earlier irrigation practice projects. The findings of CSE001 provide important quantitative data that will make a stronger case for individual farmers to make changes to irrigation practices on when and where to apply scarce water resources. The project has enabled a real time decision aid to be developed that has the potential to assist cane farmers optimise irrigation scheduling from a profitability viewpoint.

Apart from scheduling, there may be other benefits derived from this project in terms of:
- improvements to APSIM,
- potential improvements to the DAMEA$Y model,
- reduced deep drainage
- improved efficiency of investment (quantity and type) in irrigation infrastructure

These other benefits have been difficult to quantify but there are likely to be some benefits accruing from these areas in the future. In this regard the investment criteria are likely to be an underestimate of the true performance of the project.

The investment appears to have been extremely sound. Given the assumptions made for low adoption, the investment in project CSE001 and part of CSE009 still shows an expected net present value of $1.7 m, a benefit-cost ratio of nearly 2 to 1, and an internal rate of return of over 9%.
FUTURE RESEARCH NEEDS

1) Information about soil water extraction by sugarcane is scarce in Australia. This has led to confusion about the contribution to crop water requirements from water stored at depth in the profile and from water tables. The technology developed in CSE001 would be improved if soil water extraction data could be obtained at the same time that WaterSense is implemented on farms. This will allow growers to compare simulated and measured soil water deficits and will allow researchers to adjust soil water extraction coefficients in WaterSense to make it more representative of the soil types and hydraulic properties encountered. Some initial research is required to see if this concept will work.

2) While working with users of the web scheduling service we noticed that estimates of crop water use later in the crop cycle may be too high. We have used the Bowen ratio energy balance (BREB) technique to refine estimates of crop water use based on APSIM and the Penman-Monteith equation. We know that water use declines in the Ord at some stage after the wet season and suspect this may be occurring in the east as well. There are other situations where SRDC’s investment in BREB technology should be exploited to improve the relevance of the technology developed during CSE001. More work is required with the BREB to improve our equations for estimating crop water use of large or lodged crops, old ratoons, GCTB conditions and new farming systems using controlled traffic and wide row spacings.

RECOMMENDATIONS

WaterSense is the main output arising from this project and it is important to continue with its development and promotion in the industry. This is being done with funding from CSE009 at Sarina and Bundaberg with small groups of growers and extension staff who are helping us to understand what is required as we build the revised web service. The version of WaterSense described in this report allows users to run APSIM over the web to obtain optimised seasonal water use plans for each paddock on their farms. While case study growers now understand and appreciate this information they consider the current web service to be slow (40 mins per paddock) and cumbersome (one paddock at a time) and are unlikely to use it. Our interaction with Bundaberg growers indicates that they, like Ord growers, would use a service that delivers an irrigation schedule for the whole farm, rapidly over the web. Our first priority was therefore to improve the WaterBalance web service developed for Ord growers so that those with limited irrigation could also use it. Our software engineer has been working for about 10 months on a new version of WaterBalance that includes the essential components of APSIM in order to cater for crops growing under limited water conditions. However the optimisation technology developed in CSE001 will not be immediately available over the web. More software engineering is required to deliver the technology of WaterSense as described in this report, at the speed of WaterBalance as required by growers. Our understanding from the case study groups is that they will use this service if we include their requirements of speed, convenience and advice for the whole farm and for the whole water year.

We recommend that SRDC support the completion of this work and the ongoing promotion and refinement of this service in the sugar industry. The way forward has already been investigated during the CSE001 workshops with BSES and with the submission of a BSES project to promote the use of this tool. Adoption of irrigation scheduling tools including those based on capacitance probes has been slow even in high value crops using expensive water. We urge SRDC to consider the long term advantages of the wide adoption of this technology as outlined in the ‘Expected Outcomes’ section. Initial adoption may be slow but we anticipate that legislative and market requirements will eventually encourage the wide adoption of this service. The service will provide the necessary records of water use, runoff and drainage that will
eventually be required by law and possibly by markets and will allow users to claim best practice based on the best science.

REFERENCES


PUBLICATIONS


LIST OF APPENDICES

1 Tools for improving efficiency of limited water use in sugarcane
2 A web-based system for planning use of limited irrigation water in sugarcane
3 Report on results of 2002/03 farm trials at Bundaberg and Childers
4 Can lodging be controlled through irrigation?
5 Analysis of carry over effect of previous irrigation treatment on subsequent ratoon
6 Carry-over effect of irrigation from first to second ratoon
7 Improving irrigation water use in areas of northern Australia with shallow water tables
8 Simulating upflow from water tables using the soilwat2 module in Apsim
9 Strategies for optimum use of limited water revised for situations with fluctuating water tables
10 Simulated risk of germination failure from water logging
11 Modelling water stress response in sugarcane: validation and application of the Apsim-sugarcane model
12 Sugar industry irrigation workshop
13 Implications of recent SRDC funded irrigation R&D
Appendix 3

Report on results of 2002/03 farm trials at Bundaberg and Childers

Bundaberg Trial on the farm of Dave and Annette Lawson

Irrigation

Irrigation treatments were:

1) no irrigation (rainfed),
2) 2ML/ha, applied when the model indicated irrigation should best be used. This was called the ‘Capped’ treatment.
3) 2ML/ha plus credit water and water harvesting also applied when the model indicated irrigation should best be used. This was called the ‘Plus’ treatment.
4) As in (3) but applied when the grower thought it best to irrigate.

![Graphs showing rainfall and irrigation over time]

Fig 1. Rainfall and irrigation during the 2002/03 experiment on David Lawsons farm.

The crop (5th ratoon) which harvested on 13 August 2002 and again on 30 July 2003, received 760 mm rain. The allocation for the Capped treatment ran out in mid-January. The Grower treatment received additional credit water during the first irrigation and it was irrigated on three occasions in March while irrigation for the Plus treatment was delayed to April. The Capped treatment received a total of 186 mm, the Grower and Plus treatments received 302 and 280 mm respectively. This was net irrigation. The equivalent amounts for a winch system would be more like 250, 370 and 425 mm gross irrigation respectively if we regard application efficiency to be about 75%.
In the previous two experiments the irrigation regime for the Grower and Plus treatments were similar indicating that the grower was responding to crop requirement for water in a similar manner to stress calculations in the model. In this experiment the first irrigation was applied at the same time in both Grower and Plus treatments but the grower used more credit water than was allowed in the Plus treatment. The next irrigation was also applied on the same day for each treatment but the irrigation regime was different thereafter. The Grower treatment was irrigated three times in March using up the remaining allocation whereas the Plus treatment was not irrigated in March but was irrigated in April to complete the use of the remaining allocation.

**Soil water**

Soil water content was monitored to a depth of 100 cm using an Enviroscan system. The rainfed treatment extracted over 100 mm during January when rainfall was very low. High soil water deficits also developed in the Grower and Plus treatments in January but not to the same extent as in the Capped and Rainfed treatments. It is likely that irrigation during January was highly beneficial for the yield response observed in the Grower and Plus treatments. Rainfall in early February (165 mm in five days) would appeared to have filled the profile to 1 m in the irrigated treatments but not in the rainfed treatment. This difference warrants further investigation since it suggests that infiltration may be improved by irrigation. At least 130 mm infiltrated the capped treatment during the rain five days of rain.

Irrigations for the Plus treatment in April led to relatively high soil water content for this treatment as the crop matured.

![Total soil water content in the top 1 m soil for the experimental crop at David Lawson’s trial. Initial soil water contents were equalized.](image)

**Fig. 2.** Total soil water content in the top 1 m soil for the experimental crop at David Lawson’s trial. Initial soil water contents were equalized.
Results of sampling

Table 1. Crop yield components for Lawson trial

<table>
<thead>
<tr>
<th>Results of sampling 27 April 2003</th>
<th>Treatments</th>
<th>Rain</th>
<th>Capped</th>
<th>Plus</th>
<th>Grower</th>
<th>LSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green leaves per stalk</td>
<td></td>
<td>5.2</td>
<td>6.8</td>
<td>6.6</td>
<td>7.0</td>
<td>0.6</td>
</tr>
<tr>
<td>Leaf moisture %</td>
<td></td>
<td>70.8</td>
<td>69.6</td>
<td>71.3</td>
<td>70.4</td>
<td>0.64</td>
</tr>
<tr>
<td>Leaf area index</td>
<td></td>
<td>2.3</td>
<td>3.0</td>
<td>2.9</td>
<td>2.9</td>
<td>Ns</td>
</tr>
<tr>
<td>Live stalks/m²</td>
<td></td>
<td>9.7</td>
<td>9.9</td>
<td>9.9</td>
<td>10.3</td>
<td>Ns</td>
</tr>
<tr>
<td>Dead stalks/m²</td>
<td></td>
<td>0.8</td>
<td>1.2</td>
<td>1.0</td>
<td>1.2</td>
<td>Ns</td>
</tr>
<tr>
<td>Total dry biomass (t/ha)</td>
<td></td>
<td>18.5</td>
<td>23.2</td>
<td>24.3</td>
<td>26.2</td>
<td>Ns</td>
</tr>
<tr>
<td>% biomass in stalk</td>
<td></td>
<td>63.6</td>
<td>69.0</td>
<td>68.9</td>
<td>69.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Cane yield (t/ha)</td>
<td></td>
<td>43.6</td>
<td>60.1</td>
<td>63.5</td>
<td>69.1</td>
<td>11.2</td>
</tr>
<tr>
<td>Sucrose %</td>
<td></td>
<td>11.3</td>
<td>11.3</td>
<td>11.5</td>
<td>11.4</td>
<td>Ns</td>
</tr>
<tr>
<td>Sucrose % of dry stalk</td>
<td></td>
<td>41.8</td>
<td>42.0</td>
<td>43.5</td>
<td>43.5</td>
<td>Ns</td>
</tr>
<tr>
<td>Sucrose yield (t/ha)</td>
<td></td>
<td>4.9</td>
<td>6.8</td>
<td>7.3</td>
<td>7.9</td>
<td>1.4</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Results of sampling 29 July 2003</th>
<th>Treatments</th>
<th>Rain</th>
<th>Capped</th>
<th>Plus</th>
<th>Grower</th>
<th>LSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Green leaves per stalk</td>
<td></td>
<td>3.7</td>
<td>4.5</td>
<td>2.9</td>
<td>3.7</td>
<td>Ns</td>
</tr>
<tr>
<td>Leaf moisture %</td>
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<td>65.0</td>
<td>66.0</td>
<td>65.3</td>
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<tr>
<td>Leaf area index</td>
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<td>1.8</td>
<td>1.9</td>
<td>2.3</td>
<td>2.3</td>
<td>Ns</td>
</tr>
<tr>
<td>Live stalks/m²</td>
<td></td>
<td>8.2</td>
<td>8.5</td>
<td>9.2</td>
<td>9.3</td>
<td>Ns</td>
</tr>
<tr>
<td>Dead stalks/m²</td>
<td></td>
<td>0.7</td>
<td>0.9</td>
<td>0.8</td>
<td>0.9</td>
<td>Ns</td>
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<tr>
<td>Total dry biomass (t/ha)</td>
<td></td>
<td>25.1</td>
<td>29.8</td>
<td>33.3</td>
<td>35.4</td>
<td>3.9</td>
</tr>
<tr>
<td>% biomass in stalk</td>
<td></td>
<td>66.8</td>
<td>71.1</td>
<td>74.5</td>
<td>70.5</td>
<td>Ns</td>
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<tr>
<td>Cane yield (t/ha)</td>
<td></td>
<td>52.0</td>
<td>64.6</td>
<td>75.5</td>
<td>76.6</td>
<td>9.2</td>
</tr>
<tr>
<td>Sucrose %</td>
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<td>16.6</td>
<td>17.0</td>
<td>17.5</td>
<td>16.7</td>
<td>Ns</td>
</tr>
<tr>
<td>Sucrose % of dry stalk</td>
<td></td>
<td>51.1</td>
<td>51.8</td>
<td>53.4</td>
<td>51.3</td>
<td>Ns</td>
</tr>
<tr>
<td>Lodge angle</td>
<td></td>
<td>10.0</td>
<td>17.5</td>
<td>21.3</td>
<td>17.5</td>
<td>Ns</td>
</tr>
<tr>
<td>Sucrose yield (t/ha)</td>
<td></td>
<td>8.7</td>
<td>11.0</td>
<td>13.2</td>
<td>12.8</td>
<td>1.7</td>
</tr>
</tbody>
</table>

LSD = Difference required for statistical significance

When the crop is erect green leaf number is a good indication of the degree of water stress suffered by the crop. In April there were fewer green leaves in the rainfed crop than in the other treatments and there were no differences between the other (irrigated) treatments. Leaf moisture content was significantly higher in the Plus treatment than the other treatments probably because this treatment had recently been irrigated. The Plus treatment also had a significantly higher leaf moisture content than other treatments in July. This indicates that the delayed irrigation regime in the treatment helped to keep the crop in better condition than the other treatments. This did not show up in the green leaf numbers in July probably because the Plus treatment was more lodged than the other treatments. The Plus treatment may have had a higher sucrose content in July than the other treatments and this may have led to a higher sucrose yield than the other treatments. There were actually no statistically significant differences between the Plus and Grower treatments in regard to cane and sucrose yield and sucrose content but it seems that there...
was some benefit of the delayed irrigation treatment as scheduled by computer. In addition the Plus treatment used less water than the Grower treatment.

Summary.

In the two previous experiments, the grower and Plus irrigation schedules were similar but the Grower yields were higher and in one case this was significant. In this trial the computer schedule was quite different to that of the grower in that it held off irrigation until April while the grower completed his irrigation in March. In this trial the Plus treatment was if anything slightly better than the grower treatment.

The combined results indicate that the computerised scheduling technique tends to mimic how a good grower would schedule irrigation but in some unusual rainfall years it may do a slightly better job than the grower. The results support the use of this technique at least for planning ahead over the water year for when to use limited irrigation and possibly for planning ahead over a period of weeks when next to irrigate a given paddock. The technique could be used to plan irrigation for a number of key crop classes and soils on the farm and other paddocks in similar conditions could be irrigated before or after these key paddocks are irrigated depending on the limitation of the irrigation infrastructure.
Childers Trial on the farm of Graham and Sandra Webb

Irrigation
The whole site was irrigated in September with approximately 40 mm. Irrigation treatments were:
1) no further irrigation (rainfed),
2) 2ML/ha, applied when the model indicated irrigation should best be used. This was called the ‘Capped’ treatment.
3) 2ML/ha plus credit water and water harvesting also applied when the model indicated irrigation should best be used. This was called the ‘Plus’ treatment.
4) As in (3) but applied plus extra irrigation when the grower turned the pump in for other blocks. This was called the ‘Extra’ treatment.

Fig 3. Rainfall and irrigation during the 2002/03 experiment on Graham Webbs farm.

Rainfall for the 5th ratoon crop was 657 mm which was very low. Total net irrigation for the Rainfed, Capped, Plus and Extra treatments was 40, 223, 301 and 379 mm. The main difference between the Capped and the Plus treatments was the additional irrigations received by the plus treatment in December and June. The Extra treatment received additional irrigations in January and April.

Soil water
The soil dried out considerably in January despite two or three irrigations applied at this time. Soil water extraction in the rainfed treatment was probably close to the maximum possible given that the rate of extraction was very low before relieving rains came in February. Another irrigation was warranted in January. The scheduling procedure was ‘expecting’ at least some rain in January. It is possible that a more regular update of the schedule would have called for an irrigation to prevent soil water extraction exceeding 100 mm which probably reduced yields in all irrigated treatments. Differences in soil water content between treatments were small after the February rains. However large differences were noted from May to July. Unfortunately the April sample of the Extra treatment was taken around the Enviroscan tubes so the high soil water content in this treatment after April was due to the lack of cane surrounding the tubes.

![Graph showing total soil water content in the top 1 m soil for the experimental crop at Graham Webb’s trial. Initial soil water contents were equalized.](image)

**Fig. 4.** Total soil water content in the top 1 m soil for the experimental crop at Graham Webb’s trial. Initial soil water contents were equalized.

In a previous experiment it was shown that yield was reduced when soil water extraction at a depth of 40 cm slowed down and when extraction at 100 cm increased. This happened for in January over a period of about 20 days for the rainfed crop. Stress periods defined in this way for the other treatments were short lived (Fig 5).
Fig. 5. Water content at 40 cm (solid line) and 100 cm (broken line) for four treatments in Graham Webb’s trial. Shaded area shows where yield may have been reduced.

It was suspected from previous results that the rainfed crop was extracting water below the depth of the deepest Enviroscan sensor at 1 m. Two deep Enviroscan tubes were installed in one rainfed plot in December 2002. The deepest sensor was now at 2.8 m. It soon became apparent that the rainfed crop was extracting water readily at 1.5 m and then at 2.0 m and 2.8 m during dry conditions in January. Extraction at these depths occurred before soil water content in shallower layers became critical. The crop stopped extraction below 2 m as soon the rains in February started. These rains helped to replenish soil water at depth. The crop then used this deep water gradually after March.
Results of sampling

Despite the low rainfall irrigation had no significant effect on Cane or Sucrose yield (Table 2). The only significant effects of irrigation were on leaf characteristics. The number of green leaves in April were lower in the Rainfed than the other treatments. In July green leaf numbers were reduced in the Rainfed and the Extra treatments. Lodging normally results in a drop in green leaf numbers but in this case lodging was more severe in the capped and Plus treatments than in the Extra treatment.

The soil water measurements help to explain why there was little impact of irrigation on yield. If we consider the stress criteria developed in the last experiment based on extraction patterns at 40 and 100 cm, it seems that there was not a great deal of water stress experienced in the rainfed plots. This is almost certainly due to the access that roots had to water stored at 2.8 m and possibly deeper. From the extraction patterns below 1 m it is easy to see how 100 mm or more could have been supplied to the crop during January from these depths. This is equivalent to two additional irrigations.
Table 2. Crop yield components for Webb trial

<table>
<thead>
<tr>
<th>Component</th>
<th>Rain</th>
<th>Capped</th>
<th>Plus</th>
<th>Extra</th>
<th>LSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green leaves per stalk</td>
<td>5.8</td>
<td>6.3</td>
<td>6.1</td>
<td>6.6</td>
<td>0.2</td>
</tr>
<tr>
<td>Leaf moisture %</td>
<td>73.0</td>
<td>72.8</td>
<td>72.3</td>
<td>72.9</td>
<td>NS</td>
</tr>
<tr>
<td>Leaf area index</td>
<td>3.1</td>
<td>3.1</td>
<td>3.1</td>
<td>3.3</td>
<td>Ns</td>
</tr>
<tr>
<td>Live stalks/m²</td>
<td>10.8</td>
<td>10.3</td>
<td>10.5</td>
<td>10.1</td>
<td>NS</td>
</tr>
<tr>
<td>Dead stalks/m²</td>
<td>0.9</td>
<td>0.8</td>
<td>0.8</td>
<td>1.1</td>
<td>NS</td>
</tr>
<tr>
<td>Total dry biomass (t/ha)</td>
<td>25.5</td>
<td>27.5</td>
<td>27.1</td>
<td>27.4</td>
<td>NS</td>
</tr>
<tr>
<td>Cane yield (t/ha)</td>
<td>93.1</td>
<td>97.2</td>
<td>99.1</td>
<td>95.6</td>
<td>NS</td>
</tr>
<tr>
<td>Sucrose %</td>
<td>5.3</td>
<td>6.3</td>
<td>5.2</td>
<td>5.8</td>
<td>NS</td>
</tr>
<tr>
<td>Lodge angle (deg)</td>
<td>11</td>
<td>19</td>
<td>16</td>
<td>13</td>
<td>NS</td>
</tr>
<tr>
<td>Sucrose yield (t/ha)</td>
<td>5.0</td>
<td>6.1</td>
<td>5.2</td>
<td>5.6</td>
<td>NS</td>
</tr>
</tbody>
</table>

Results of sampling 29 July 2003

<table>
<thead>
<tr>
<th>Component</th>
<th>Rain</th>
<th>Capped</th>
<th>Plus</th>
<th>Extra</th>
<th>LSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green leaves per stalk</td>
<td>5.6</td>
<td>7.8</td>
<td>5.6</td>
<td>5.4</td>
<td>1.5</td>
</tr>
<tr>
<td>Leaf moisture %</td>
<td>67.8</td>
<td>67.1</td>
<td>67.8</td>
<td>68.4</td>
<td>NS</td>
</tr>
<tr>
<td>Leaf area index</td>
<td>2.8</td>
<td>3.3</td>
<td>5.9</td>
<td>4.0</td>
<td>1.3</td>
</tr>
<tr>
<td>Live stalks/m²</td>
<td>9.6</td>
<td>9.3</td>
<td>9.8</td>
<td>9.7</td>
<td>NS</td>
</tr>
<tr>
<td>Dead stalks/m²</td>
<td>0.3</td>
<td>0.7</td>
<td>0.7</td>
<td>0.8</td>
<td>0.3</td>
</tr>
<tr>
<td>Total dry biomass (t/ha)</td>
<td>39.2</td>
<td>43.9</td>
<td>43.5</td>
<td>37.4</td>
<td>NS</td>
</tr>
<tr>
<td>Cane yield (t/ha)</td>
<td>104.7</td>
<td>111.5</td>
<td>104.3</td>
<td>103.3</td>
<td>NS</td>
</tr>
<tr>
<td>Sucrose %</td>
<td>13.3</td>
<td>13.8</td>
<td>13.7</td>
<td>12.2</td>
<td>NS</td>
</tr>
<tr>
<td>Lodge angle (deg)</td>
<td>30</td>
<td>48</td>
<td>58</td>
<td>45</td>
<td>NS</td>
</tr>
<tr>
<td>Sucrose yield (t/ha)</td>
<td>14.0</td>
<td>15.4</td>
<td>14.3</td>
<td>12.6</td>
<td>NS</td>
</tr>
</tbody>
</table>

Summary

The results of the third experiment on Graham Webbs farm confirmed earlier results that there is little response to irrigation on these very deep soils. This was so even though rainfall was low in all three experiments. The soil is able to store large amounts of rain and irrigation so that irrigation timing is not so critical in these soils. It may be worth considering reducing allocations to soils like this and using more of the allocation in poorer soils on the farm.
Appendix 5

Analysis of carry over effect of previous irrigation treatment on subsequent ratoon

The 2ML treatment in the first water production trial was irrigated last in December 2001. The trial was harvested on 2 July 2002. With the low rainfall experienced in the ‘wet’ season, the crop ratooning after harvesting could be expected to be adversely affected by these very dry conditions if a residual effect of water stress applies to the subsequent ratoon which is what most growers expect. Conversely the Full treatment was irrigated regularly until 20 May 2002. The ratoon crop would benefit from this more favourable treatment if a residual (carry over) effect from one crop to the next applies.

Total irrigation applied and last date of irrigation for six allocation treatments in the first water production experiment at Kalamia

<table>
<thead>
<tr>
<th>Treatment</th>
<th>2ML/ha</th>
<th>4ML/ha</th>
<th>6ML/ha</th>
<th>8ML/ha</th>
<th>10ML/ha</th>
<th>Full</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation applied (mm)</td>
<td>200.0</td>
<td>400.6</td>
<td>601.0</td>
<td>800.3</td>
<td>941.5</td>
<td>993.1</td>
</tr>
<tr>
<td>Last date of irrigation</td>
<td>07-Dec-01</td>
<td>25-Jan-02</td>
<td>27-Mar-02</td>
<td>24-Apr-02</td>
<td>10-May-02</td>
<td>20-May-02</td>
</tr>
</tbody>
</table>

Trickle tape was replaced soon after harvesting apart from a section (5 m x 4 rows) of each plot in which irrigation was to be excluded until after the first irrigation. Shoots were counted in a 3.0 m length of crop row over two drills in each of these sub-plots as well as in sections that were irrigated shortly after harvest according to the planned treatments for the second experiment. Shoots were counted on three occasions (1 and 23 August and 24 September).

Analysis of variance of the shoot counts indicated that previous irrigation treatment had no significant effect on shoot population at any stage regardless of whether irrigation was applied to the ratoon or not. However the trend was for shoot counts to increase with increased irrigation applied after harvesting. These results suggest that there is little residual effect of drying off conditions prior to harvest on the vigour of the subsequent ratoon. If this effect was important one would have expected a much larger response to the wide range of drying off treatments.

The residual effect will be assessed more thoroughly after completion of the second water production experiment. In this case all plots will be irrigated after harvesting and samples will be taken to determine canopy development and biomass yield. If differences exist in these attributes the ratoon will be sampled at harvest to see if these effects carry through to the final yield.
Shoot population at three stages after ratooning of the first water production experiment at Kalamia a) when no irrigation was applied after harvesting b) when irrigation was applied. Irrigation received by each treatment at each stage is shown in c).
Appendix 6

Carry-over effect of irrigation from first to second ratoon

Treatments applied to the 1st ratoon crop (see table) resulted in a wide range of periods without irrigation prior to harvesting in August 2003. The 2ML/ha treatment was not irrigated for 8 months before harvest and the Unlimited treatment was dried down only for 2 months. Rainfall for the crop was very low (557 mm).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>2ML/ha</th>
<th>4ML/ha</th>
<th>6ML/ha</th>
<th>8ML/ha</th>
<th>10ML/ha</th>
<th>Unlimited</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrig. (mm)</td>
<td>199.8</td>
<td>399.3</td>
<td>602.0</td>
<td>800.6</td>
<td>1000.3</td>
<td>1078.0</td>
</tr>
<tr>
<td>Last irr.date</td>
<td>2/12/02</td>
<td>24/12/02</td>
<td>6/1/03</td>
<td>4/2/03</td>
<td>24/4/03</td>
<td>6/6/03</td>
</tr>
</tbody>
</table>

The 2nd ratoon was irrigated uniformly starting soon after harvesting. The trial was sampled in February 2004 when the crop was five months old. At this stage it was possible to distinguish between stalks and young tillers that would eventually be shaded out. These tillers were not numerous and were not included the stalk count.

Irrigation treatments applied to the first ratoon crop had no significant effect on stalk population, cane yield or biomass of the second ratoon crop. The trend was for reduced stalk population, cane yield and biomass with increased irrigation (Fig 1). A regression of cane yield on allocation treatments (2, 4, 6, 8 and 10 ML) was just significant (p=0.05).

![Fig 1. Total fresh weight (●) and stalk count (X) per 15m2 of sample area for samples taken on 17 February 2004 in a second ratoon following a first ratoon experiment with six irrigation treatments.](image)

It was expected that dry conditions prior to harvest of the first ratoon would limit stalk numbers and yield of the second ratoon. This is not evident in the sampling data for February (Fig 1) which indicated that dry conditions favoured stalk population and yield, if anything.

At harvest of the first ratoon (August 2003), stalk population was lower for high irrigation treatments (>1000 mm) than for lower treatments. Stalk counts when the 1st ratoon was harvested (August
2003) were significantly correlated with stalk counts of the 2nd ratoon in February 2004 on a treatment mean basis but not on a plot by plot basis (Fig 2).

![Graph showing stalk counts](image)

**Fig 2. Stalks per 15 m² at 5 months for the 2nd ratoon crop versus stalks per 15 m² at the time of harvesting the 1st ratoon crop**

**Mechanism**

The mechanism proposed for the carry over effect is through stalk population and through survival of stools after lodging. A uniformity rating of each plot made on 27 October 2003 was correlated with a lodging rating made when the first ratoon was harvested (Fig. 3). Uniformity was rated low when stool tipping was observed and when stool regrowth was gappy or non uniform. Fig 4 shows a poor case of stool tipping after severe lodging in the Unlimited irrigation treatment.

![Graph showing uniformity and lodging](image)
Fig 3. Uniformity rating (0 = poor) at 2 months for the 2nd ratoon crop versus lodging index (9=fully lodged) at the time of harvesting the 1st ratoon crop

Fig 4. Example of stool tipping after severe lodging in the previous ratoon
Shallow water tables can provide substantial contributions towards meeting a crop’s water requirement. Employing an irrigation management strategy that makes use of this water will increase irrigation water use efficiency (IWUE) and potentially reduce groundwater recharge from irrigated fields. This paper describes a simulation study undertaken to identify the degree to which shallow water tables reduce the response in sugarcane yields to irrigation. Sugarcane was chosen as water is the major limitation to sugarcane production and little is known about the influence of shallow fresh water tables on irrigation in that industry. Data on the response of sugarcane yield to differing irrigation applications were obtained from two experiments. Yields in these experiments were simulated with the APSIM-Sugarcane model parameterised to represent a water table in the root zone. Measured yields were simulated accurately. Then, irrigation response curves were simulated for a range of soil types, climates and water table depths to assess how irrigation can be reduced in the presence of a shallow water table. Shallow water tables reduced crop yield response to irrigation in all the combinations of soil types and climates simulated. The results confirmed those previous experiments and limited modelling, that water tables at 1 m depth can supply the water requirements of sugarcane in many environments, and deeper (2 m) water tables may supply half the crops’ needs. To benefit from shallow water tables, water table depth must be monitored and scheduling methods should be based on measurements of either soil water status or relative crop growth rates.

Introduction

Upflow from shallow water tables can be a significant component in the root zone water balance of many cropping systems (Benz et al., 1984; Meyer et al., 1989). Shallow water tables are often associated with problems of salinity, acidity or waterlogging. However, where the water in the water tables is of good quality and is deep enough to avoid waterlogging, shallow water tables should be viewed as a potential water resource for crops. If these conditions exist in irrigation areas, irrigation can be reduced with no detriment to crop yield (Patel and Joshi, 1985; Hunsigi and Srivastava, 1977; Ayars and Hutmacher, 1994; Stacey et al., 2003), so increasing irrigation water use efficiency.

In Australia, sugarcane is mainly grown along the north-eastern tropical and sub-tropical coastline and shallow water tables, either permanent or temporary, are a common feature of these landscapes (Sweeney et al., 2001). Irrigation is necessary to achieve maximum sugarcane production in many of these regions (Tilley and Chapman, 1999). However, the sugar industry has generally focussed only on the negative aspects of shallow water tables, such as waterlogging (Rudd and Chardon, 1977) and salinity (Kingston, 1993), and neglected their potential as a water resource. Recently, Hurst et al. (2004) reviewed the impact of shallow water tables on irrigation management in sugarcane production systems and suggested that much or all of the crop’s water requirements could be met.
from shallow water tables in many situations. In the Australian sugar industry, this conclusion is supported by results from three field experiments where water tables were known to be shallow (Inman-Bamber et al., 1999; Stacey et al., 2003; Inman-Bamber, 2004). However, there needs to be broader testing of the concept to underpin the development of innovative irrigation management practices to maximise irrigation water use efficiency in regions with shallow, fresh water tables.

Because of the paucity of experimental data, Hurst et al. (2004) used a modelling approach to make generalisations about the possible impact of shallow water tables on irrigation management. They used the one-dimensional water balance model SWIMv2.1 (Verburg et al., 1996) in which plants are represented as a ‘sink’ in the water balance equation, the strength of which is simply related to the canopy development and the evaporative potential of the environment. Thus, they were not able to investigate any interactions between irrigation management, upflow and sugarcane crop growth. In this study we use a more detailed modelling approach, employing the dynamic crop growth and soil water modelling capabilities in the APSIM-Sugarcane cropping systems simulator. The aim of this paper is to better define the amounts of irrigation required in Australian sugarcane production systems in the presence of shallow, fresh water tables, through simulating irrigation production functions for a range of soil types, climatic zones and water table depths.

**Materials and Methods**

**Experimental Sites**

The effect of shallow water tables on irrigation was examined at an experiment in two regions, Bundaberg and the Burdekin. The Bundaberg experiment was conducted over two seasons (2000-2001 and 2001-2002) on the 3rd and 4th ratoons of a Q151 crop on a Red Kandasol located at the Fairymead Mill farm of Bundaberg Sugar. Details of methodology and some of the results from this experiment have been reported by Stacey et al. (2003), but a brief description follows. A randomised plot design was used with three irrigation treatments and five replicates. The three irrigation treatments were full irrigation, half irrigation and rainfed. Irrigation was applied daily by sub-surface trickle irrigation. The amount applied (I) was based on the previous day’s evapotranspiration from the crop, and was estimated from:

\[
I = F \cdot E_{\text{pan}} \cdot K_c
\]

where \( F \) is the fraction applied (i.e. 0.8 for full irrigation, 0.4 for half irrigation), \( E_{\text{pan}} \) is daily class A pan evaporation, and \( K_c \) is a crop factor determined by the crop growth stage. The final yield at harvest was determined from mill bin weights.

The Burdekin experiment was conducted in the 1999-2000 season on the 2nd ratoon of a Q96 crop located on a Black Vertosol at Field 97 of the Kalamia Mill farm of CSR Sugar. Details of methodology have been reported by Inman-Bamber (2004), but a brief description follows. A randomised split plot design was used with varieties Q96 and Q124 as the sub-plot treatment, and two irrigation treatments (irrigated and rainfed) as the whole plot treatment. There were five replications. Due to an outbreak of orange rust in the Q124 treatment, only the Q96 treatment was sampled. The irrigated treatment received 100mm of water on 13 May, 3 Jun., 5 Jul., 25 Jul., 8 Aug., 23 Aug. and 9 Sep. 2000. The experiment was furrow irrigated. The crops were hand-sampled eight times throughout growth.

\[1\] All soils are described according to the Australian soil classification (Isbell 1996).
Modelling

Modelling was undertaken in two phases. The 1st phase aimed to determine the accuracy with which the experimental results could be simulated with a cropping systems model. The 2nd phase aimed to use the model to generalise the results of the experiment by simulation of a range of soil type, climate and irrigation management scenarios. Simulations were undertaken with the APSIM cropping systems simulator (Keating et al., 2003). The model was configured to consist of modules for soil water (APSIM-SoilWat; Probert et al., 1998), for soil N and C dynamics (APSIM-SoilN; Probert et al., 1998), and sugarcane residue (APSIM-Residue; Thorburn et al., 2001) dynamics, and sugarcane growth (APSIM-Sugarcane; Keating et al., 1999). The dynamics of water, N, C and roots are simulated in soil layers, with water (and associated nitrate) moving between layers where gradients exist. The presence of a shallow water table was approximated by ensuring that the bottom soil layer remained saturated. This was achieved by (1) preventing downward drainage from this layer, and (2) adding 5mm of water to the bottom soil layer every day to replace losses from upward flow and uptake by roots.

In modelling the experimental results, the soil profiles from both the Fairymead (Red Kandosol) and Kalamia (Black Vertosol) experiments were divided into 8 layers with a total depth of 1.2m. Water table depths were set at 1m for both sites based on measurements at the experiments. Parameters for the soil water model (e.g., water holding capacities, etc.) and the soil N model (soil organic matter, C/N ratio, etc.) were based, wherever possible, on measured data.

Simulations were also conducted for a combination of four water table conditions, three soil types, three climates and five irrigation application amounts. The soil parameters were taken from the soil types at the Fairymead and Kalamia experiments (Red Kandosol and Black Vertosol), as well as a finer textured Brown Deromosol used in sugarcane production simulations by Thorburn et al. (2004). Climate data from Bundaberg, Ayr and Ingham were used, these being areas where sugarcane is irrigated and shallow water tables are most common (Sweeney et al., 2001). The climate at these locations also spans a range of rainfall and evaporative conditions (Table 1). The climate data were obtained from the Queensland Department of Natural Resources, Mines and Energy Silo patched point datasets (Jeffrey et al., 2001). The cropping cycle simulated consisted of a 15 month plant crop (planted mid-April) plus four 13 month ratoons. Simulations were run for a 30 year period, starting in 1970. A range of irrigation applications was obtained by using five values of F (0, 0.2, 0.4, 0.6 and 0.8) in Equation 1. F = 0 equates to rainfed conditions. Irrigation was applied every 14 days, with the amount applied calculated by summing the results of Equation 1 over that period. Water table depths of 1m, 1.5m, 2m as well as no water table were simulated for all nine soil type x climate combinations and for each irrigation treatment.

Table 1. Daily mean solar radiation and annual mean rainfall and evaporation and range (in parentheses) for Ingham, Ayr and Bundaberg.

<table>
<thead>
<tr>
<th>Location (lat., long.)</th>
<th>Years</th>
<th>Radiation (MJ/m²/d)</th>
<th>Rainfall (mm)</th>
<th>Evaporation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingham (18.65oS, 146.18°E)</td>
<td>1901-2001</td>
<td>19.1 (17.8 – 21.3)</td>
<td>2100 (798 – 3725)</td>
<td>2106 (1501 – 2790)</td>
</tr>
<tr>
<td>Ayr (19.58oS, 146.18°E)</td>
<td>1901-2001</td>
<td>19.7 (19.0 – 21.6)</td>
<td>1035 (261 – 2432)</td>
<td>2060 (1800 – 2317)</td>
</tr>
</tbody>
</table>
Results

Simulations of experimental yields

There was close agreement between the observed and simulated yields for the 3rd and 4th ratoons of the Fairymead experiment (Figure 1). In all treatments there was no response to applying irrigation water both in the observed and simulated results.

As with the Fairymead experiment, the simulated yields for the Kalamia experiment also generally agreed with the measured values (Figure 2). There was a tendency for yields to be underestimated early in the season and overestimated at harvest. However, these differences were generally close to the magnitude of experimental error. Over estimation of final yields can also be attributed to the effects of lodging and other factors that limit yield, but are not considered in the model.

Figure 1. Comparison of simulated (lines) and observed (symbols) stalk biomass and cane yields for 3rd and 4th ratoons at Fairymead for the three treatments: a) full irrigation; b) half irrigation; and c) rainfed. Bars about the measured data points show ± standard deviation.

Figure 2. Comparison of simulated (lines) and observed (symbols) stalk biomass and cane yields for 2nd ratoons at Kalamia for a) irrigated and b) rainfed treatments. Bars about the measured data points show ± standard deviation.
Simulations of impact of shallow water tables

The presence of water tables had the greatest effect on simulated yields for the Ayr climate (Fig. 3a, b, c), with the greatest difference in yield occurring in the Brown Dermosol soil (Fig 3c). In this soil, the simulated rainfed yield of 58 t/ha increased to 165 t/ha when a water table was present at a depth of 1m. Across all soils, the simulated responses to irrigation (i.e. the slopes of the lines in Fig. 3a, b, c) were also generally greatest with the Ayr climate. The low rainfall, high evaporative demand and high radiation at Ayr (Table 1) result in both a large irrigation requirement (Robertson et al., 1997) and a large yield (Muchow et al., 1997). Thus it is not surprising that shallow water tables had the greatest impact on rainfed yield responses to irrigation.

The greatest difference in simulated yields for the Bundaberg and Ingham climates also occurred with the Brown Dermosol soil (Fig 3f, i). In this soil there was little simulated yield response to increasing irrigation with a water table at 1 m depth. In the other two soils, yields were simulated to increase with increasing irrigation with all water table conditions, although the increase was markedly lower than that for the Ayr climate. It is interesting to note that sugarcane yields in the long term simulations for the Red Kandasol and Bundaberg climate (Fig. 3e) were substantially greater than those measured in the experiment at Fairymead (Fig. 1). This difference arose because of the specific climatic conditions and the decline in stalk numbers (and hence radiation use efficiency) during the ratoon crops in the experiment. These conditions were captured in the simulation of the experimental results through the climate data and measurements in the experiment, but not in the long term simulations.

There was little difference between yields simulated with no water table and yields simulated with a water table depth of 2m for the Red Kandosol and Brown Dermosol soils for the Bundaberg and Ingham climates (Fig 3e, f, h, i). This may indicate that a water table at a depth of 2 m may be too deep to provide additional water to the crop for these soil types and climates. The difference between the yields simulated without a water table and with a water table at a depth of 2 m for the Black Vertosol (Fig. 3d, g) may indicate that sugarcane crops on this soil type were able to access more water at 2m.

For the Brown Dermosol soil and all climates (Fig. 3c, f, i) the rainfed yields simulated with a water table at a depth of 1m were higher than the yields simulated without a water table that received the maximum amount of irrigation. This indicates that irrigation could be reduced or stopped without any major impact on yield when the water table is 1m from the surface on this soil type.
Figure 3. Simulated average cane yields for different irrigation amounts when no water table was present (●), depth to water table = 1m(●), depth to water table = 1.5m(▲) and depth to water table = 2m(★) using a) Black Vertosol and Ayr climate parameters; b) Red Kandosol soil and Ayr climate parameters; c) Brown Dermosol soil and Ayr climate parameters; d) Black Vertosol and Bundaberg climate parameters; e) Red Kandosol soil and Bundaberg climate parameters; f) Brown Dermosol soil and Bundaberg climate parameters; g) Black Vertosol and Ingham climate parameters; h) Red Kandosol soil and Ingham climate parameters; i) Brown Dermosol soil and Ingham climate parameters.

Discussion
This study confirms earlier conclusions (Patel and Joshi, 1985; Hunsigi and Srivastava, 1977; Stacey et al., 2003) that shallow, fresh water tables can supply all, or much of the irrigation requirements of sugarcane. In addition, this study also shows the important impacts of climate and soil type, a fact not obvious from the limited number of experiments conducted on this issue. For example, simulated sugarcane yields with the Ayr climate responded markedly to irrigation in the Black Vertosol and Red Kandosol soils with a water table at 1 m depth (Fig. 3a and b). So the shallow water tables did not meet all the crops’ water demands in these soils contrary to expectations from experimental results. The Ayr climate is characterised by high radiation and potential evaporation (Table 1), resulting in high irrigation requirements and potentially high yields. In a less demanding climate, such as Bundaberg, crop water requirements are almost fully met by a water table at 1 m depth in these soils (Fig. 3d and e). The soil type
impacts on water table contributions to crop requirements are dependant on water table depth, being most pronounced in Fig. 3 at the shallowest depth. However, in all soil and climate scenarios shown in Fig. 3, the presence of a water table reduces the crop yield response to irrigation. Thus in many circumstances, it will be important for farmers to consider water tables in their irrigation management plans.

This raises the question of how irrigation management plans should be changed to account for water tables. For example, if crops are obtaining all their water requirements from shallow water tables, irrigation will not raise yields and so will not be necessary. Alternatively, if crops are likely to obtain half their water from shallow water tables, either the irrigation amount or frequency should be reduced. An important issue to consider in framing management plans is the likely yield that will be obtained in the crop being irrigated. The long-term simulations (Fig. 3) depict potential yields; those that would be obtained without the limitations of pests, diseases, lodging, crop damage during harvest, etc. Thus they represent maximum demand for water. Where yield limitations occur any or all of these effects, as exemplified by the reduced yield of the 4th ratoon crops in the Fairymead experiment (Fig. 1), the crop’s water demand may be reduced and so shallow water tables will meet a greater proportion of the crop’s requirements. For example, if a sugarcane crop growing on a Black Vertosol at Ingham was expected to yield 70 t/ha, the simulation results in Fig. 3g suggest that a fresh water table could supply all the crop’s water needs unless the water table was below 1.5 m depth. Given that commercial sugarcane yields in Australia are often well below potential yields (Muchow et al., 1997) it is likely that fresh water tables will be able to meet crops water needs in many situations.

Another important factor in forming irrigation management plans will be knowledge of the depth and quality of water in the water tables. Sugarcane irrigators rarely monitor water table depth. Izuno et al., (1988) describe a float pole for use in shallow wells to visually indicate water table depths without the need for direct measurement. The use of these poles has been promoted in irrigation areas within the sugar industry where the potential for shallow water tables is greatest (Fig. 4).

Knowing if water tables are present is also important in deciding on the appropriate approaches to irrigation scheduling. Concepts of replenishing a soil water reservoir as it becomes depleted are unable to be applied to root zones where upflow is a significant component in the water balance. In these circumstances direct measurement of soil water conditions or relative plant growths rates will be more useful.

Finally, it should be remembered that the range of soil types considered in this study is relatively small, being based heavily on soils at experiments undertaken in sugarcane growing regions in Queensland. One soil type not included in this study is very slowly permeable soils, such as occur in areas such as the Ord River Irrigation Area. The results should not be applied to such soils.
Figure 4: A float pole with coloured increments to indicate particular irrigation events in a sugarcane paddock in Queensland. The construction is shown in the diagram (after Izuno et al. 1988).

Acknowledgements
This work was supported by Land and Water Australia, National Program for Irrigation Research and Development.

References


Appendix 8

Simulating upflow from water tables using the SOILWAT2 module in APSIM

Results from a trickle irrigation experiments at Fairymead (Bundaberg Sugar) indicated that the water table which was often at a depth of 1m or less, contributed substantially to crop water requirement. A detailed soil physical model (SWIM) has been parameterized in order to account for up flow of water to roots above a water table (Sweeney et al., 2002). The use of SWIM requires considerable knowledge of soil physical properties. We attempted using the SOILWAT2 module in APSIM to simulate water up flow from the following much simpler algorithms.

Diffusivity = \( a + \exp(b \cdot 0_{av}) \)

Where \( a \) and \( b \) are soil specific constants and \( 0_{av} \) is the average available soil water content of the saturated layer (water table) and the layer above the water table.

Up Flow = diffusivity \( \times (0_{sat} - 0)/z \)

Where \( 0_{sat} \) is the water content of the saturated layer, \( 0 \) is the water content of the layer above the saturated layer and \( z \) is the depth of this layer.

The above steps were repeated for all layers above the water table so that roots which may be some distance from the water table can access the up flow.

This procedure was used to assess the contribution of a water table to crop yield in a dry-down experiment at Kalamia. In this experiment some plots were irrigated regularly after the wet season in 1999/2000 (wet) and others were not irrigated at all (dry). The height of the water table near this experiment was measured by placing a piezometer (pressure transducer) in a perforated tube at a known depth below the soil surface. The water table rose rapidly after large rain events to within 500 mm of the soil surface on two occasions (Fig 1). The water table was at about 1.5 m for the second half of the experiment.

Simulations were carried out with and without a water table at 1.5 m. Roots were allowed to grow to within 600 mm of the water table.

The following steps were required to simulate a watertable using SOILWAT2.

1) The following command was provided in the manager parameter file so that 5mm water could be added to layer 8 every day.

\[
\text{Soilwat2 set dlt_sw_dep = 0 0 0 0 0 0 0 5}
\]

2) SWCON for layer 8 was set to zero so that soil in this layer would remain saturated apart from when upward flow and uptake by roots occurred.

The presence of a water table did not change the simulated results a great deal (Figs 2 & 3). Both simulations were reasonably accurate. Simulation of the dry treatment was improved slightly by invoking the upflow algorithms.

It was possible to parameterize the soil SOILWAT2 module to obtain accurate simulations of the Fairymead and Kalamia experiments where water tables were present.
This is the first time that this has been done with SOILWAT2 as far as is known. Modellers have mostly resorted to more complex models such as SWIM to simulate upflow in the past. It is now possible to simulate scenarios where water tables may be present in order to assess responses to irrigation and to forecast or hindcast yields as well as other applications. For many applications the current capabilities in SOILWAT2 are probably sufficient given that we cannot predict the temporal and spatial nature of water tables in most situations. However in situations where the height of the water table is known (Ord for example) care would need to be taken in setting parameters such as distance of roots from the water table, lower limit of water extraction and the coefficients in diffusion algorithms.

![Graph showing water table depth over time](image)

**Figure 1.** Depth of the water table in a dry down experiment at Kalamia
Figure 2. Measured (symbols) and simulated (lines) stalk biomass in wet and dry treatments of the Kalamia experiment assuming no water table.

Figure 3. Measured (symbols) and simulated (lines) stalk biomass in wet and dry treatments of the Kalamia experiment assuming a water table at 1.5 m.

Reference
Appendix 9

Strategies for optimum use of limited water revised for situations with fluctuating water tables

Fresh water tables can contribute substantially to crop water requirement. Considerable effort has been expended in this project and a linked project with LWA to assess the extent of this contribution. A paper outlining the progress is provided in Appendix 5. An important factor in forming irrigation management plans will be knowledge of the depth and quality of water in the water tables. Sugarcane irrigators rarely monitor water table depth. The attached paper describes a float pole for use in shallow wells to visually indicate water table depths without the need for direct measurement.

Simulations were performed to assess the effect of the presence of a water table on timing for the best use of limited water using the Fairymead climate record obtained from the ‘Patched point’ data set of the SILO database base from BOM. Allocations of 0, 1, 2, 3 and 4 ML/ha were applied to a September ratoon crop in the simulations. A water table at 1.0 m in Red Ferrosol was simulated. Simulations were also conducted in the presence and absence of lodging. A water table had a larger effect on the best time to use limited water when allocations were low compared to when allocations were high, as may be expected (Fig. 1). With low allocations (1 and 2 ML/ha) and no water table, most of the water was required for regeneration of the ratoon crop. In the presence of a water table, low allocations were more useful during the high evaporative demand period, December to February. With high allocations (3 and 4 ML/ha) and a water table, growers could afford to use more of the allocation in February and March and less in November and December compared to a situation where no water table was present. Lodging was not prevalent to any great extent in the simulations and did not influence the best time to use limited water.

The Caneoptimiser software is now being adapted to accommodate the effects of a water table on best use of limited water.
Fig 1. Best time to use limited water allocations of 1, 2, 3 and 4 ML/ha for a September ratoon for situations where a water table is present at 1.0 m (closed symbols, ●▲) or absent (open symbols, ○△) or where lodging was simulated (▲△) and not simulated (●○).

To complete the picture it is interesting to note the effect of water table on response to irrigation (Fig 2). The water table contributed to an additional yield of about 40 t/ha at low allocations and about 30 t/ha at high allocations.

Fig 2. Simulated cane yield in response to increased allocation for situations where a water table is present at 1.0 m (closed symbols, ●▲) or absent (open symbols, ○△) or where lodging was simulated (▲△) and not simulated (●○).
Appendix 10
Simulated risk of germination failure from water logging

Assumptions:

1) Establishment was deemed to be complete when leaf area index exceeded 0.05.
2) Planting was simulated for the first day of each month excluding the period May to August when planting is not normally carried out.
3) Soil water at planting was set at 50% of total plant available water capacity (PAWC).
4) Waterlogging was deemed to have started when soil water content in the top 40 cm soil was at or above the drained upper limit.
5) Germination was deemed to have failed if the soil was waterlogged for more than four days. Details of the soil hydraulic properties used in the simulation are shown in Table 1.
6) Simulations were conducted with and without irrigation in the establishment period.
7) For the irrigation treatment, 25 mm was applied if the soil water deficit was greater than 30 mm provided 14 days had lapsed since the last irrigation.

Table 1. Soil hydraulic properties for a red dermosol used in the simulation. DUL and LL15 = water content at -10 and -1500 kPa respectively. Sat = saturated water content. Sw = soil water content at planting. BD= bulk density. Runoff wf = runoff weighting factor, SWCON = saturated conductivity (fraction per day).

<table>
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<tr>
<th>Depth (mm)</th>
<th>Air_Dry (mm/mm)</th>
<th>LL15 (mm/mm)</th>
<th>DUL (mm/mm)</th>
<th>Sat (mm/mm)</th>
<th>Sw (mm/mm)</th>
<th>BD (g/cc)</th>
<th>Runoff wf</th>
<th>SWCON</th>
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<td>0.368</td>
<td>1.5</td>
<td>0</td>
<td>0.001</td>
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</tbody>
</table>
Probability of germination failure with and without irrigation for various regions

**Childers**

![Graph showing probability of germination failure for Childers with and without irrigation.]

**Sarina**

![Graph showing probability of germination failure for Sarina with and without irrigation.]

- TREAT
  - irrigate
  - noirrigate
Macknade (Ingham)
Mareeba
## Appendix 12

**Sugar industry irrigation workshop**

Arranged by BSES and CSIRO, sponsored by SRDC and CRC IF

Illawong Resort, Mackay, March 3, 4: 2004

<table>
<thead>
<tr>
<th>Time</th>
<th>#</th>
<th>Activity</th>
<th>Presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1</td>
<td>08.00</td>
<td>Welcome</td>
<td>Tony Linedale, Jeremy Cape</td>
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<tr>
<td></td>
<td></td>
<td>Introductions, workshop aims and procedures</td>
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<td></td>
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<td>Opening address</td>
<td>Ross Gilmour, Jim Sullivan, Rob Sluggett, Brad Hussey, Mandy Jeppesen, Peter Sutherland, Greg Shannon, Drewe Burgess</td>
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<tr>
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<td><strong>Session 1 Best Management Practice</strong></td>
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<td>Each region to describe;</td>
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</tr>
<tr>
<td></td>
<td>3</td>
<td>• current BMP recommendations</td>
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<tr>
<td></td>
<td>4</td>
<td>• key issues to resolve</td>
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<td>Discussion – what do we keep and what don’t we know about improving BMP?</td>
<td>Jeremy Cape</td>
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<td>Morning tea</td>
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<td><strong>Session 2 Scheduling and drying off</strong></td>
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<td>Evaporation standards for sugarcane</td>
<td>Steve Attard</td>
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<td>Stress thresholds for reduced irrigation</td>
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<td>Optimum timing of limited irrigation</td>
<td>Geography</td>
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<td>Discussion – implications for BMP</td>
<td>Jeremy Cape</td>
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<td>12.30</td>
<td>Lunch</td>
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<td><strong>Session 3 Software tools - Concurrent hands on session</strong></td>
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<td>Web based scheduling for full irrigation</td>
<td>Steve Attard</td>
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<tr>
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<td>Web based scheduling for supplementary irrigation</td>
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<td>Dam EaSy</td>
<td>Maurie Haines</td>
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<td>WETUP</td>
<td>Peter Thorburn</td>
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<td>15.00</td>
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<td><strong>Session 4 When is increased irrigation economic?</strong></td>
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<td>Additional water supply options - storages</td>
<td>Maurie Haines, Tony Linedale</td>
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<td>Impact of irrigation on marginal returns</td>
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<td>Lodging and response to irrigation</td>
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<td>Application efficiency</td>
<td>Maurie Haines, Phil Charlesworth</td>
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<td>Deep drainage in the Burdekin Delta</td>
<td>John Hughes &amp; Tony Crowley</td>
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<td>Soil electrical conductivity and yield</td>
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| 19.15 (7pm) | **Day 1** | Brad Hussey  
Drewe Burgess  
John Turner  
Jeremy Cape |
| 08.30  | **Session 6 Water Use Efficiency**                                   | Graham Harris               |
| 08.45  | Adopting BMP in the cotton industry; research to practice            | Graham Harris               |
| 10.15  | **Session 7 Engineering**                                            | Trevor Willcox  
Erik Schmidt  
Keith Bristow  
Jeremy Cape  
Graham Harris |
| 12.30  | **Session 8 NPSI Knowledge Management Project**                       | Jeremy Cape/Tony Linedale  
Jeremy Cape  
Graham Harris |
| 15.00  | **Session 9 Bringing it all together**                               | Jeremy Cape  
Jeremy Cape |
|        | Summarise and review previous sessions                               |                             |
|        | Next steps research                                                  |                             |
|        | Next steps extension                                                 |                             |
|        | Industry panel                                                       |                             |
|        | Workshop review and evaluation                                        |                             |
|        | Close Workshop                                                       |                             |
|        | Afternoon tea                                                        |                             |
Sugar industry irrigation workshop, Arranged by BSES and CSIRO, sponsored by SRDC and CRC IF
Illawong Resort, Mackay, March 3, 4: 2004
Report

This workshop provided an opportunity for all those involved in irrigation R&D to share current knowledge and experiences and to plan for future R&D to influence the sugar industry with this knowledge. A total of 33 presentations were made to about 40 delegates over two days. Slides of the presentations and points of discussion of groups of these presentations are provided in Appendix. These points were gathered together in the last session and actions were then highlighted for various delegates to undertake.

Some of the main points of general discussion were as follows.
Best management practice (BMP) needs to consider regional variation and that BMP is not static but is a continuous improvement process. BMP needs to be widened to encompass triple bottom line accounting. BMP issues need to be identified for the region concerned and leadership from the cane growing community needs to drive BMP to resolve these issues. We need to establish pathways for increasing adoption and technical support for this process can come through partnerships between R&D agencies and communities.

Irrigation is part of the farming system including soil management, weed control and implementation of new farming systems. Irrigation extension efforts must be linked across the industry particularly in relation to the promotion of new farming systems. Resources need to be shared across R&D programs to do this.

This is an issue of reviewing BMP standards. Who is responsible for this?

Performance reporting based on measuring and monitoring after benchmarking is required. This implies continuous improvement in irrigation practice. Advisers (both public and private) and irrigators need to develop the benchmark practice. Researchers need to develop the tools for measuring and monitoring and farmers, advisors and researchers need to put these tools in place.

Coordinating and sharing information needs to be improved both within and outside sugar industry. Funds ($30 000) should be sought to run an annual forum like this one. Such funds could be requested from BSES, SRDC and QDRN&M. The sugar industry needs to be represented in the CRC IF and it needs to be actively involved in the Northern zone, promoting the aims of the CRC IF.

Interpretation of Research Information to Growers should result in conversion of research outputs into practice change. Research outputs can be captured on CD as in the RWUE CD produced by Steve Raine. This information should be updated and promoted during RWUE2. Researchers need to ensure that their research is linked to end users. Researchers need to understand current irrigation practice. Improved links between researchers, extension and farmers will ensure that information flows both ways. End user information needs to be acknowledged and valued by researchers. For this, researchers need to develop skills in communication and interaction with end users and both parties need to understand each other's, aspirations, knowledge and needs.

Other more specific issues were discussed under the questions of what, how and who:

Timing of irrigation
What? In the case of limited infrastructure and water, crop demand exceeds the capacity of water supply. Critical times to water need investigation and promotion.

Who? Research and extension need a strategy for continued awareness of core issues developed by a project after the project is terminated. The people to do this are RPAC/RWUE/Extension Officers/CPPB staff.

Managing irrigation and salinity
What?
- Knowing the quality of water used and it’s impact on cane production
- Matching irrigation quantity to crop needs to prevent rising water tables
- Minimising off site impacts
  - Runoff
  - Deep drainage
  - Erosion

How?
- Tools to demonstrate to growers the effect of their practices on the environment
• Self assessment of practices (land water management plan)
  Plans → WUE2
  Independent Auditing → Industry
• Economic benefits of environmental BMP
  Who? Grower group activity → Extension Officers

_Scheduling in High Input Systems_

What are we scheduling for?
  Maximum sugar yield or $ return vs the environment.
How do we schedule?
  • Monitoring soil water content, knowing water holding capacity of soil and plant water use. We need to review of conventional thinking in high input systems. Further trials and demonstrations may be required for this.
Who?
  • Agencies involved include CSIRO, BSES, Growers, CANEGROWERS, RWUE etc.

_Improving Labour Efficiency of Irrigation_

How
  • By customise existing technology
  • Extend current technology – i.e. +ve and –ve experiences from other growers and look at other industries
Who
  Agribusiness growers consultants, engineers (NCEA, RWUE1)

_Data for irrigation Management of Alternate Row Systems_

How
  • Identify and collate existing data
  • Establish the gaps in existing data
  • Fill gaps eg trials, monitoring of existing crops
Who
  Sugar services, CSIRO, BSES YDJV, RWUE2

_Infrastructures for Supplementary Irrigation_

What
  • Risk management
  • How much money do I spend when you don’t know how much water you have/need
How
  • Climate/stream flow / DAMEASY / APSIM / design economics → in MODELS
  • Simple guidelines for extension officers
Who
  CSIRO, sugar services, JCU, BSES , RWUE1
**Improving Adoption of Existing Knowledge**

**How?**
- Increase of information exchange between researchers, extension officers and growers
  NB NOT a one way street (participatory research)
- Factor in economics

**Who?** Researcher, extension officers, growers and millers

**Technical Support for Equipment Suppliers**

**How?**
- Transfer of knowledge (Research Extension Officers) to irrigation equipment suppliers
- Suppliers work together research/extension officers

**Who?** Suppliers, researchers and extension officers

**On/off Farm Infrastructure**

**What?**
- Limits to BMP adoption
  - Economics of on farm: (capital investment) change + OFF farm
  - Reliability of the whole system

**Who?** Economists, engineers and extension officers

**Limited Water**

**What?**
- Right time, place and amount
  Biophysical elements (better use of rainfall, water tables soil water etc)
  Attitudes to risk
- Engineering
  Application efficiency
  Cycle time
  start-up- related to infrastructure design

**Economic Assessment Awareness**

**What?**
- Partial Budgeting
- Marginal response to:
  Additional water
  Storage
  Infrastructure
  Operational variables

**How?**
- More business like approach to irrigation

**Who?**
- Users
- Extension officers
Providers

Interaction of Water and Fertilizer

What?
- Independent of:-
  - Type of fertilizer
  - Way it is applied
  - Irrigation system
- Two key issues i.e. Matching the use of
  - Crop requirement –fertilizer
  - Technique of application

Who? Researchers, extension officers, growers

Conflicting Value of Water to Different Sector of Industry

What?
- Managing sugar yield verses tonnage
- Understanding payment system – millers, growers and researchers

How? Develop new payment system that suits growers and miller

Who? Millers, growers

Drainage Management and Disposal

What?
- Volume of water draining below the root zone
- Quality
- Impact on ground water systems
- Downstream impacts
- Surface drainage
  - Runoff
  - Volume
  - Quality
  - Sediments
  - Nutrients
  - Pesticides

Industry Capacity to Handle Irrigation

What?
- Education of irrigation Practitioners
  - Growers
  - Suppliers – agribusiness
- Number and skill capacity of researchers and adoption people (RD&E continuum) in industry
- Cultural issues and change management
Butchers Paper Comments from Mackay irrigation Workshop
3 to 4 March 2004

1 Irrigation Best Management Practice Issues

- Economic assessment awareness
- Limited water
- On/Off Farm Infrastructure
- Coordinated approach to information
- Technical support for equipment suppliers
- Improved adoption of existing knowledge
- Simple tools that work well
- Measure to match inputs for crop requirements
- Potential value for precision agriculture

2 Apsim (Scheduling and drying off)

Positive potential

Regional differences
Further testing
- Weeds
- Water quality
- Varieties
- Disease
- Lodging

Rules of thumb and interpretation
Links to current practice

3 Infrastructure for supplementary irrigation

- Data for irrigation management for alternative row spacing
- Improved labour efficiency of irrigation
- Scheduling in high input systems
- Innovation
- Managing irrigation/salinity

4 Irrigation efficiency experience issues

- Hi density impact on irrigation practice
- Deep drainage – future off site impacts
- Measurement and monitoring at a relevant scale
- Some irrigators know how to manage irrigation
- Don’t assume they know what you are talking about
- Irrigation optimising drying off to maximise $ returns
- Identify principles across regions
- Tools for measuring applications rates
- Suitable delivery systems
- Awareness of variation of blocks
- Performance reporting
- Break crops
- Better management of existing environment – particularly rainfall/weeds
- BMP in context

Conflict value of water in different sectors
- Sugar v’s CCS v’s Tonnes
- Environmental water flows - Sunwater commercial or managers
- Understanding payment systems and how it effects behaviour – possibly need better system
Last Session Identification of Issues

1 BMP in Context

- Acknowledge regional variation
- As a continuous improvement process
- Within wider context encompassing the triple bottom line

Actions

- Identify issues for the region ➔ leadership from canegrowers to drive it
- Establish pathways for increasing adoption ➔ technical support through partnerships

2 Better Management of Existing Environment – practically rainfall and weeds

Irrigation is part of the farming system including
- Soil management
- Effective rainfall
- Weed control

a) Ensure irrigation extension efforts are linked to
- Active involvement in similar programs
- Sharing of resources $$$$ 
- Promote farming system

Resulting EO’s

b) BMP module inter linked in overall farm BMP
- BSES BMP officers

Who reviews BMP?

4 Performance Reporting

- Measuring and monitoring
- Evaluating benchmarking and baseline
- Continues improvement

Who:-
- Develop baseline ➔ advisers (both public and private) and irrigators
- Tools ➔ researchers
- Monitoring (evaluation systems in place) ➔ farmers advisors and researchers

5 Coordinating Information Sharing

- Share within and outside sugar industry
  - Inside ➔ annual forum/report ➔ $30000

  BSES ➔ central allocation of funds from:-
Outside – BSES
Representation of sugar people on CRC
Zone coordination groups ➔ Extension officer’s industry people with interests

6 Interpretation of Research Information to Growers

I.e. Conversion of research outputs into practice change

a) Capture research outputs eg RWUE CD
   RWUE2 maintain and update RWUE1 CD

b) Promote RWUE CD – current information
   i.e. in RWUE 2

c) Ensure research is linked to end users
   i.e. researcher involvement with end user

8 Researchers Understanding Current Practice

- Improved links between researchers, extension and farmers – form partnerships (information needs to go both ways)
- Value end user information

a) Skill researchers in communication and interaction with end users
   Understand each others
   Aspirations
   Knowledge
   Needs

b) Research teams led by a useful project leader

9 Timing of Water Use

a) Timing of irrigation
   - In the case of limited infrastructure – crop demand exceeds the capacity of supply water
   - Promote Message:- identify critical times to water eg
     Establishment
     Main growing period
     Crushing (drying off)
     Following rainfall events – infrastructure early start
   - Research/extension – need strategy for continued awareness of core issues once project dies
   - Who RPAC/RWUE/Extension Officers/CPPB

b) Managing irrigation and salinity
• Knowing the quality of water used and it’s impact on cane production
• Matching irrigation quantity to crop needs to prevent rising water tables
• Colation of existing knowledge to develop grower friendly guidelines
• Who ?????????

c) Environmental
• Minimising off site impacts
  Runoff
  Deep drainage
  Erosion
• All research is done?
• Tools to demonstrate to growers the effect of their practices
• Self assessment of practices (land water management plan)
  Plans → WUE2
  Independent Auditing→ Industry
• Economic benefits of environmental BMP
• Who:- Grower group activity → Extension Officers

10 Environmental Issues

• Timing of water use
• Research understanding current practices
• Future of industry→ economics
• Interpretation of research
  Info→ Growers
• Sharing of solutions between GPS
• Better understanding of risk

13 Scheduling in High Input Systems

Issue ???? what are we scheduling for

• Economics eg maximise sugar/yield
  Environment

How
• Monitoring Water holding capacity of soil
  Plant water use etc
  Review of conventional thinking in high input systems
• Further trials –if required – extension

Who
• CSIRO, BSES, Growers, Cane Growers, RWUE etc

14 Improving Labour Efficiency of Irrigation

How
• Customise existing technology
• Extend current technology –i.e. +ve and –ve experiences from other growers and look at other industries
Who: Agribusiness growers consultants, engineers → NCEA, RWUE1

G

15 Data for irrigation Management of Alternate Row Systems

How
- Identify and collate existing data
- Establish the gaps in existing data
- Fill gaps eg trials, monitoring of existing crops

Communication

Who → sugar services, CSIRO, BSES YDJV RWUE2

16 Infrastructures for Supplementary Irrigation

Issues
- Risk management
- How much money do I spend when you don’t know how much water you have/need

How
- Climate/stream flow / DAMEASY / APSIM / design economics → in MODELS
- Simple guidelines for extension officers

Who: CSIRO, sugar services, JCU, BSES ,RWUE1

17 Improving Adoption of Existing Knowledge

- Increase of information exchange between researchers, extension officers and growers NB NOT a one way street
  Solution participatory research
- Factor in economics

Who → Researcher, extension officers, growers and millers

18 Technical Support for Equipment Suppliers

- Need for more
- Transfer of knowledge (Research Extension Officers) to irrigation equipment suppliers
- Suppliers work together research/extension officers

WHO
- Suppliers, researchers and extension officers

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→ Limits to BMP adoption
• Economics of on farm:- (capital investment) change + OFF farm
• Reliability of the whole system

Who → economists, engineers and extension officers

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• Right time, place and amount
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• Partial Budgeting
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  Way it is applied
  Irrigation system
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  Technique of application
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• Understanding payment system – millers, growers and researchers

Solution :- Develop new payment system that suits growers and miller

Who:- millers ,growers
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- Volume of water draining below the root zone
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- Surface drainage
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  - Pesticides

27 Industry Capacity to Handle Irrigation

- Education of irrigation Practitioners
  - Growers
  - Suppliers – agribusiness
- Number and skill capacity of researchers and adoption people *(RD&E continuum)* in industry
- Cultural issues and change management
Other topics not ranked to comment on in groups

3 Break crops

7 Future of industry/economics

12 Innovation

19 Coordinated approach to information

23 Policy Framework of State and Federal Gov
IRRIGATION BEST PRACTICE PRINCIPLES
BUNDABERG

APPROACH

1. Utilise all available allocation to:
   (a) Reach yield potential
   (b) Maximise profit
2. Use all sources of available water:
   - OFWS, recycled water
   - Use stored water first


Yield and Water Use
Bundaberg 1998 - 2002

\[ y = -1.3588x^2 + 16.296x + 53.002 \]

\[ R^2 = 0.5751 \]

Effective rainfall, irrigation and yield, Bundaberg 1989-1999

Crop Water Index, Bundaberg, 1988-2001

CWI = Cane yield/(effective rainfall + irrigation)

3. Maximise effectiveness of rainfall
   - Increased infiltration
   - Improved retention
   - Appropriate start-up times
1 Best practice Principles

4. Appropriate system designs for irrigation requirement

5. Monitor practical indicators (soil, water, growth etc) to understand irrigation requirement

**BMP PRINCIPLES**

**MANAGEMENT**

1. Program irrigation practice to meet seasonal demand (water deficit)

2. Apply target volume of RASW according to peak demand for crop stage

3. Start up irrigation after rain when storage capacity (relative to RASW) is reasonable; irrigate where greatest capacity exists first
1 Best practice Principles

<table>
<thead>
<tr>
<th>ISSUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Client understanding of irrigation economics</td>
</tr>
<tr>
<td>• Establishment of critical compaction levels</td>
</tr>
<tr>
<td>• Relationship of soil moisture to high density planting systems demands</td>
</tr>
<tr>
<td>• Monitoring for better management</td>
</tr>
</tbody>
</table>
Barriers to Adoption BMP Irrigation

- State of industry
- Cost of irrigation has increased
- Allocations – Trend to use less water
- Growers prioritise other crops (eg peanuts, soybeans, small crops) instead of cane
- Most farms have insufficient infrastructure

Messages and Issues in the ISIS/MARYBOROUGH Region

Isis District Announced Allocations
(as % of Nominal Allocations)

<table>
<thead>
<tr>
<th>Year</th>
<th>Initial</th>
<th>Final</th>
<th>Credit Water</th>
<th>% Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998-99</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1999-00</td>
<td></td>
<td></td>
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<tr>
<td>2000-01</td>
<td></td>
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<tr>
<td>2001-02</td>
<td></td>
<td></td>
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<tr>
<td>2002-03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003-04</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Industry Initiatives

ISIS TARGET 100
MARYBOROUGH "85 IN 5"

Isis Target 100 Issues
These issues are part of the Isis Strategic Plan which is an initiative of Isis CG, Isis Mill & Isis CPPB

1. Farming Systems
2. Plant Stand
3. Disease Levels
4. Nutrition
5. Water Management
   6. Weed Control
   7. Varieties
   8. Harvesting
   9. Benchmarking and Economics

Water Management Issues

1. Using water
   - Promote use of irrigation water. Good discussion topic at cell groups.
   - To demonstrate the benefits of applying water to sugar cane crops to 100 growers by 2004.
2. Water use efficiency

- Promote **WUE BMP** by:
  - maintaining enviroscans at 6 sites
  - e’scan data on mill web site – weekly in season
  - provide weekly local newspaper irrigation update
  - maintain two display boards
  - good topic at cell groups
  - assist the WUEI#2

3. System changes

- Assess the value of at least one system change:
  Measure productivity increase vs costs.
  Potential topic for cell groups

### Extension Activities - ISIS Target 100
- 4 enviroscans in different varieties & crop classes
- Use of enviroscan data for
  - updating roadside display boards
  - weekly water use data/stories in local paper
  - fortnightly water use update on ABC radio
  - water use update in local CG newsletter
- Irrigation guide
- System changes
- Appointment of Judy Skilton, RWUEI – 17 Feb 04
- Active extension by BSES, Productivity Board and Mill Productivity Officer

### Main Messages

- 50 mm Irrigation every 8 days (full canopy, mid summer)
- Need to irrigate heavily in main growing season (summer) until mid April, then re-assess.
- 1 megalitre water = 10 tonne cane.
- Start irrigation after heavy rain within 8 days.
- Growth Rate information

### Isis System Changes

- Centre Pivots – 4
- Lateral Moves – 2
- Bird Perches (Boom) – about 20
- Drip Installations - 8
- RWUEI – last 2 years

<table>
<thead>
<tr>
<th>Number of Installations</th>
<th>Total Value</th>
<th>RWUEI Subsidy</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 (3 CP, 4 Drip, 1 LM, 3 Boom)</td>
<td>$886,290</td>
<td>$132,330</td>
</tr>
</tbody>
</table>

### Isis Land & Water Management Plans

- 6 Courses totalling 75 growers (out of 180)
- Have to confront 79 pages of irrigation BMP questions.
- In particular, have to calculate:
  1. Capacity of their irrigation infrastructure.
  2. Calculate the theoretical potential water use.
  3. Calculations to determine the efficiency of their irrigation management
Extension Activities - MARYBOROUGH REGION

- 4 enviroscans to be installed shortly in M’gh
- Use of enviroscan data regular water use updates through
  - M’gh CANEGROWERS newsletter
  - local shed meetings & field days
  - local BSES & Productivity Board extension staff
- Appointment of Judy Skilton, RWUE2 - 17 Feb 04
Sugar Industry Irrigation Workshop March 2004

Plane Creek

- Supplementary Irrigation
  - 70% of area able to be irrigated (Once!)
  - 1 scheme (Kinchant)
  - restricted allocations last few years
  - 0.5ml/ha

Recent Activities

- High Pressure gun uniformity
- Flow meter use – application rates
- Growth & tensiometers
- Timing of limited use
- Improving WHC – controlled traffic, min till, pre-mounding
- PAM – improving infiltration & quality of runoff

Polyacrylamide (PAM)

- Potential improvements in infiltration
- Less soil movement from field
- Less movement of sediment-bound chemicals and nutrients
Irrigation in Mackay

Water resources

<table>
<thead>
<tr>
<th>Water source</th>
<th>Capacity</th>
<th>Allocation</th>
<th>Current Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinchant Dam</td>
<td>62 800</td>
<td>52 000</td>
<td>42%</td>
</tr>
<tr>
<td>Teemburra Dam</td>
<td>147 000</td>
<td>46 500</td>
<td>28%</td>
</tr>
<tr>
<td>Coastal bores</td>
<td></td>
<td>43 000</td>
<td></td>
</tr>
<tr>
<td>Farm dams</td>
<td>30 000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unregulated supply</td>
<td>16 000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Key issues

- 100 000 ha land
- 187 000 ML water
- Average 1.87 ML/ha
- Actual
  - 3 ML for 60 000 ha
  - 40 000 ha dry land
- Bores are currently limited to 3 nights pumping per week and volumetric allocation.

Key issues

- Irrigation water requirement
  - 3 to 8 ML per ha (volume)
  - 50mm per week (application rate)

Key issues

LIMITED WATER
Key issues

• Limited water has led to limited investment in irrigation infrastructure
• Result
  – Can not schedule irrigation on many farms

Current BMP

• Start irrigating early
• Irrigate at every possible opportunity (pumping restrictions, wind, electricity cost)
• Match irrigation application rate to soil water holding capacity
• Water valuable cane first (plant and young ratoons)
Principles of BMP for the Proserpine area:

- From RWUEI (1), the issues of Right Amount, Right Place, Right Time were promoted heavily. These still remain areas to target for extension activities.

Areas to Address in the Proserpine Region:

- Use of scheduling tools to determine when to commence irrigation following a rainfall event.
- Use of water meters to determine amount of water applied.
- Increase cup size and reduce cup numbers to reduce runoff and deep drainage losses.
- Utilise alternate row and/ or surge irrigation to reduce runoff and deep drainage losses.
- Use catch cans to determine wetting patterns and application efficiency of overhead systems.

Issues for Growers

- Mimosa pigra present in the Peter Faust Dam
  - Weed is currently being contained
  - Should the dam be quarantined, the water will also be quarantined.

Issues for Growers:

- Water quality of bores being used for irrigation:
  - Many bores being used for irrigation recorded high levels of salt during the dry period.
  - Growers were reporting salt-affected patches in cane paddocks.

Issues for Growers

- Irrigation Cycle Length
  - Irrigation cycle on the majority of farms is too long to maintain active growth.
  - This is due to either water availability or infrastructure restraints.
  - Growers are aware of this but are unable to improve.

Issues for Growers

- Dam Capacity
  - Peter Faust Dam is currently at 33% capacity.
  - During the dry period, the dam was dropping 10% per month.
  - At approximately 20% capacity, allocation will be reduced to 60%.
Issues for Growers

• Cost of Irrigation
  - A number of growers are wondering how much irrigation should be applied before they start ‘buying’ their crop.
  - This will be of greater importance as the sugar price drops.

• Saline and Sodic Soils
  - Poor patches in cane blocks (due to salt or soda) were more evident during the dry conditions.
  - Areas of previous expansion have occurred on marginal sodic country. Much of this is furrow irrigated and the use of ameliorants has been warranted.

Issues for Growers

• Liquid One Shot and Irrigation Strategies
  - Concerns have arisen regarding the quality of runoff from paddocks fertilised with LOS and then furrow irrigated.
  - Use of this product is increasing in the Proserpine district and is expected to continue with the future production of mixes containing phosphorus.

• Furrow Irrigation of Heavy Soils Under GCTB
  - With only 61% of the 2003 crop harvested green, despite dry conditions, questions have arisen as to why this is occurring.
  - Growers have stated that they cannot furrow irrigate heavy soils efficiently under GCTB systems.

Issues for Growers:

• Water Requirements under Dual Row systems:
  - A number of growers in the Proserpine area are trialling dual row systems on their farm.
  - A concern has arisen as to whether water applied through furrow irrigation is wetting up the whole bed.
  - There have also been questions regarding the difference in water requirements for dual row vs. 1.5 metre centres.

Issues for Growers:

• LOS and Irrigation Strategies:
  - SSP in conjunction with CSR Distilleries are planning trials to investigate the fate of nutrients and runoff water quality on paddocks treated with LOS and irrigated using both high-pressure overhead and furrow systems.
  - This trial will be established during 2004.
Experiments addressing these issues:

- Furrow irrigation of heavy soils under GCTB:
  - A local grower has developed an implement that splits the trash blanket and forms a V-shaped groove in the furrow to improve furrow irrigation efficiency on heavy clay soils.
  - SSP is intending to determine efficiency gains from undertaking this management practice.

Experiments that address these issues:

- Water quality of bores being used for irrigation:
  - SSP has undertaken numerous water quality tests for growers who are concerned about their bore water.
  - Regular monitoring of those of concern has been undertaken, with SSP providing recommendations to growers regarding the use of the water.

Experiments that address these issues:

- Irrigation of dual row cane:
  - A trial is to be established during 2004 to compare water requirements of both dual row and single row systems.
  - This will include the use of EnviroScans and growth measurements to determine water use of both treatments and wetting patterns of furrow irrigation systems.
Burdekin Irrigation

BMP

- Scheduling
- Application amount – Uniform inflow rates, furrow shape, GCTB management
- Soil Health - amelioration
- Recycling – pit management
- Levelling
- Water Quality – conjunctive use

Scheduling

- Intensive in the Burdekin due to access to irrigation water from Burdekin Falls Dam and underground
- Therefore gains from better timing of irrigation are potentially greater than in other areas
- Targeted by RWUEI as high gains possible with little cost

Steps towards BMP

- Aim to improve productivity for water used.
- Every farm is different but some steps are:
  1. Calibration to minipan or tensiometers
  2. Change inflow rates
  3. Change furrow shape
  4. Check/ improve water quality
  5. Recycling
- Sometimes only one of these is needed

Grower Comment/ Experience

“10 – 14 day irrigation cycle reduced to 7 days led to productivity increase of 28%”

Issues

- Water Quality
- Deep drainage
- Soil health - 30% of BRIA are sodic soils - 12% of Delta are surface sealing
- Water supply and costs
Issues

• Lack of lateral soakage has impacted negatively on performance of 1.8m dual row
• Even though much of the region has infiltration problems GCTB is not common

Results of Scheduling
Grower changed irrigation cycle only.

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Time</th>
<th>Yield t/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 – 10 days</td>
<td>11 – 16 hrs</td>
<td>131 (2002)</td>
</tr>
<tr>
<td>(Experience)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 days</td>
<td>6 - 6.5 hrs</td>
<td>156 (2003)</td>
</tr>
<tr>
<td>40 kpa</td>
<td>6 – 6.5 hrs</td>
<td></td>
</tr>
</tbody>
</table>

• Calibrating to variety and irrigating accordingly. He no longer irrigates to a set sequence of blocks.

Results

Other Observations:
• 4 irrigations to fill recycle pit as opposed to 1
• 2001- used allocation plus temporary transfer (13 ML/ha allocation/ 1950 ML)
  2002 - sold 200 ML and had 500 left over
  2003 - to the end of the 2nd quarter (December) still had more than ½ allocation left to last to harvest.
SUPPLEMENTARY IRRIGATION IN THE HERBERT

- Ingham Line
- Stone River
- Approximately 150 growers

- Supplementary irrigation – over head systems.
- 1 flood irrigation
- 2 Lateral move
- Most growers have access to 2ML
Irrigation BMP - Tablelands

- Schedule irrigations using soil moisture probes or evaporation pans calibrated to crop growth, ensuring applications do not exceed the water holding capacity of the soil profile.
- Recycle tailwater from furrow irrigation to ensure off-farm runoff does not exceed 10 percent of irrigation inflow.
- Direct excess irrigation tailwater through recycling storages to trap suspended sediments before discharge off farm.
- Minimize off-farm runoff of irrigation waters with overhead irrigation through row direction and/or contouring to avoid row slopes above 2 percent.
- Use subsurface pipelines and/or surface fluming/pipelines to reticulate irrigation water about the farm.

Adapted from “BSES sustainable sugarcane production guidelines for the development of Land and Water Management Plans in the MDIA.”

Area of overhead irrigated sugarcane tripled in 5 years

<table>
<thead>
<tr>
<th>Area of overhead irrigated sugarcane tripled in 5 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent of sugarcane area - 1998</td>
</tr>
<tr>
<td>Furrow</td>
</tr>
<tr>
<td>5297 hectares</td>
</tr>
</tbody>
</table>

Issues – Mareeba Dimbulah Irrigation Area

- Insufficient water allocation to meet crop water demand in below average rainfall years.
- On & off farm infrastructure unable to supply water as demanded by crop.
- Limited use of soil moisture probes and/or evaporation pans to schedule irrigations.
- Economics of irrigation at low sugar prices.
- Water pricing.
- Restricted allocations during dry years.
- Potential loss of water allocation for urban and environmental uses.
Evaporation Standards for Sugarcane

Steve Attard

International Standards

• Internationally accepted standard to estimate crop water use is FAO56.
• Around the world many crops, including sugarcane, utilise evapotranspiration estimates to successfully implement irrigation scheduling tools.
• International irrigation research over the past 30 years has progressed to develop accurate and reliable estimates of crop water use.
• South African sugarcane farmers currently access this technology over the web.

Sugarcane standards

• Amount of water lost from the soil profile through
  – Evaporation at the soil surface; and
  – Transpiration of the plant
• Accurate measures of water use:
  – Lysimeter
  – Bowen Ratio Energy Balance (BREB)
  – Eddy correlation

Reference ET from grassed surface (ET₀)

Develop sugarcane

\[ K_{c} = \frac{ET_{c}}{ET_{0}} \]

Crop factors, \( K_{c} = \frac{ET_{c}}{ET_{0}} \)

Swaziland \( K_{c} = 1.29 \)
Kalamia \( K_{c} = 1.23 \)
Reference ET from grassed surface (ET0)

ET from BREB in sugarcane crop (ETC)

Develop sugarcane crop factors, \( K_c = \frac{ETC}{ET0} \)

\( K_c \) for plant crops
\( K_c \) for burnt ratoon crops
\( K_c \) for gctb ratoon crops

Crop factors, \( K_c \)
- trashed and bare surfaces,
- plant or ratoon crops, and
- crop start date

\( ETC = K_c \times ET0 \)

AWS site 1
\( ET0 \)

AWS site 2
\( ET0 \)

AWS site 3
\( ET0 \)

Block 1 - Crop water use (ETC) of an Apr plant crop

Block 2 - Crop water use (ETC) of an Aug plant crop

Block 3 - Crop water use (ETC) of a Jul ratoon crop
Rainfall  Irrigation  Stalk growth
Full Point  Target deficit  Sd
Managing irrigation by stress thresholds

- Reduce irrigation
- Save labour and costs
- Increase CCS

Methods

- Two dry-down experiments
  - Spring/Summer on April ratoon
  - Autumn/Winter on Nov ratoon
- Q96 and Q117
- Kalamia, Burdekin

Spring/Summer on April ratoon

Relative stalk elongation

<table>
<thead>
<tr>
<th>Date</th>
<th>Rain, (mm/d)</th>
<th>Green leaves per stalk</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 Dec</td>
<td>90</td>
<td>6</td>
</tr>
<tr>
<td>9 Dec</td>
<td>60</td>
<td>9</td>
</tr>
<tr>
<td>29 Nov</td>
<td>30</td>
<td>12</td>
</tr>
<tr>
<td>19 Nov</td>
<td>60</td>
<td>15</td>
</tr>
</tbody>
</table>

Spring/Summer on April ratoon

Green leaves per stalk

<table>
<thead>
<tr>
<th>Date</th>
<th>Rain, (mm/d)</th>
<th>Total biomass (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 Oct</td>
<td>90</td>
<td>50% stalk elong.</td>
</tr>
<tr>
<td>10 Oct</td>
<td>60</td>
<td>25% stalk elong.</td>
</tr>
<tr>
<td>30 Sep</td>
<td>30</td>
<td>1 leaf lost</td>
</tr>
</tbody>
</table>

Autumn/Winter on Nov ratoon

Relative leaf elongation

<table>
<thead>
<tr>
<th>Date</th>
<th>Rain, (mm/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 Oct</td>
<td>90</td>
</tr>
<tr>
<td>10 Oct</td>
<td>60</td>
</tr>
<tr>
<td>30 Sep</td>
<td>30</td>
</tr>
</tbody>
</table>
Stress thresholds

- 50% stalk elongation – no yield loss
- 30% stalk elongation – no sucrose yield loss
- Loss of more than 1 leaf per stalk
  - biomass yield loss (summer)
  - Increased CCS (winter)
- Loss of more than 4.0 leaves per stalk
  - Max CCS accumulation due to stress
  - Max sucrose yield advantage
Further research showed that risk of yield loss up to 10th leaf stage is small provided irrigation is applied after planting or harvesting.
Summary

• Matching supply and demand is possible
• Saving water also possible
  – Use deep soil water after good wet
  – Reduced demand after lodging
  – Enhanced CCS can makes up for loss in cane yield
  – Crop can withstand early stress
When to use limited water – when to start up after rain

Based on the APSIM - Sugarcane model
## Methods

### Lawson and computer schedules

- **2000/01 Experiment**
  - Computer treatment: 11.1 t sucrose/ha
  - Grower treatment: 12.2 t sucrose/ha
- **2001/02 Experiment**
  - Computer treatment: 10.4 t sucrose/ha
  - Grower treatment: 12.1 t sucrose/ha

### 2002/03 Experiment

- Rainfall
- Computer treatment: 12.8 t sucrose/ha
- Grower treatment: 13.2 t sucrose/ha

### Applications of this technology

- ‘Caneoptimizer’ web system
  - Date for next irrigation(s)
  - Pre-season planning for irrigation
  - General rules of thumb
**Best bet Use of Limited Water**

**Late Ratoon - October Cycle (2 ML/Ha)**

- **Forecast in September**
- **October Cycle (2 ML/Ha)**

**Rules of thumb**

- Early cut blocks more likely have enough moisture to ratoon
- Late cut blocks need an irrigation for establishment
- Early cut blocks focus is November to February
- Late cut blocks irrigate from January onwards tapering down to May
Irrigation was applied at an efficiency of 75% and the soil moisture at crop start date estimated to be 50%. The saved met data for this paddock ends at 28-Feb-2004. The first irrigation after this date is irrigation number 2. Calculations are based on a crop start date of 01-Oct-2003 and an anticipated harvest date of 01-Jun-2004. Irrigation was applied at an efficiency of 75%, and the seed moisture at crop start date estimated to be 50%.

This prediction is based on weather data up to 26-Feb-2004 and equal future crop irrigation amounts of 30mm. 43 years of long term weather data was used in the simulation to optimise the result. Total irrigation has been restricted to 300mm. The saved met data for this paddock ends at 26-Feb-2004, with a prediction at 29-Feb-2004 and standard deviation of 8 days.

**SUMMARY OF IRRIGATION DATES:**

<table>
<thead>
<tr>
<th>Date</th>
<th>DAS</th>
<th>IRRIG#</th>
<th>OCCURS</th>
<th>DEVIATION</th>
<th>IRRIG.QTY</th>
<th>ACCUM.IRRIG</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004-05-15</td>
<td>0 days</td>
<td>1</td>
<td>100%</td>
<td>0 days</td>
<td>0 mm</td>
<td>120 mm</td>
</tr>
<tr>
<td>2004-05-16</td>
<td>10 days</td>
<td>2</td>
<td>74%</td>
<td>174 days</td>
<td>30 mm</td>
<td>240 mm</td>
</tr>
<tr>
<td>2004-07-05</td>
<td>259 days</td>
<td>3</td>
<td>93%</td>
<td>96 days</td>
<td>30 mm</td>
<td>210 mm</td>
</tr>
<tr>
<td>2004-05-20</td>
<td>293 days</td>
<td>4</td>
<td>93%</td>
<td>89 days</td>
<td>30 mm</td>
<td>180 mm</td>
</tr>
<tr>
<td>2004-05-02</td>
<td>275 days</td>
<td>5</td>
<td>95%</td>
<td>70 days</td>
<td>30 mm</td>
<td>150 mm</td>
</tr>
<tr>
<td>2004-04-30</td>
<td>250 days</td>
<td>6</td>
<td>100%</td>
<td>39 days</td>
<td>30 mm</td>
<td>120 mm</td>
</tr>
<tr>
<td>2004-04-27</td>
<td>239 days</td>
<td>7</td>
<td>100%</td>
<td>32 days</td>
<td>30 mm</td>
<td>90 mm</td>
</tr>
<tr>
<td>2004-02-29</td>
<td>212 days</td>
<td>8</td>
<td>100%</td>
<td>8 days</td>
<td>30 mm</td>
<td>60 mm</td>
</tr>
</tbody>
</table>

Optimal irrigation date using 300mm limit:

- 2003-11-15: 14 days, 1 irrigation, 100% occurrence, 0 days, 30 mm, 30 mm

Optimized yield using 300mm limit:

- Minimum is 69, maximum is 120, with median of 85 tonnes per hectare.
- Minimum is 150mm, maximum is 300mm, with median of 225mm.

This prediction is based on weather data up to 26-Feb-2004 and equal future crop irrigation amounts of 30mm. 43 years of long term weather data was used in the simulation to optimise the result. Total irrigation has been restricted to 300mm. The saved met data for this paddock ends at 26-Feb-2004, with a prediction at 29-Feb-2004 and standard deviation of 8 days.

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<td>174 days</td>
<td>30 mm</td>
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<td>259 days</td>
<td>3</td>
<td>93%</td>
<td>96 days</td>
<td>30 mm</td>
<td>210 mm</td>
</tr>
<tr>
<td>2004-05-20</td>
<td>293 days</td>
<td>4</td>
<td>93%</td>
<td>89 days</td>
<td>30 mm</td>
<td>180 mm</td>
</tr>
<tr>
<td>2004-05-02</td>
<td>275 days</td>
<td>5</td>
<td>95%</td>
<td>70 days</td>
<td>30 mm</td>
<td>150 mm</td>
</tr>
<tr>
<td>2004-04-30</td>
<td>250 days</td>
<td>6</td>
<td>100%</td>
<td>39 days</td>
<td>30 mm</td>
<td>120 mm</td>
</tr>
<tr>
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<td>30 mm</td>
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IMPACT OF IRRIGATION ON MARGINAL RETURNS

**YIELD AND WATER USE RELATIONSHIP**
Bundaberg 2001

5 Year Average

<table>
<thead>
<tr>
<th>ML/ha</th>
<th>tc/ha</th>
<th>Water use 3.07 ML/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>53</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>68</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>80</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>90</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>96.5</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>100.5</td>
<td>6</td>
</tr>
</tbody>
</table>

Effective rain 820mm

**CROP RESPONSE X PROFIT RELATIONSHIPS**

**WATER CHARGES**
BUNDABERG 2004

<table>
<thead>
<tr>
<th>Source of Water</th>
<th>Access</th>
<th>Use</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface water</td>
<td>9.28</td>
<td>5.36</td>
<td>14.64</td>
</tr>
<tr>
<td>River</td>
<td>29.68</td>
<td>18.98</td>
<td>48.58</td>
</tr>
<tr>
<td>Channel</td>
<td>1.35</td>
<td>1.35</td>
<td>2.70</td>
</tr>
<tr>
<td>Groundwater</td>
<td>3.35</td>
<td>4.35</td>
<td>7.70</td>
</tr>
</tbody>
</table>

**OPERATING RETURNS FROM IRRIGATION**

<table>
<thead>
<tr>
<th>Irrigation</th>
<th>Yield Year Av.</th>
<th>Irrigation costs based on 4.5 ML/ha</th>
<th>Operational profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>ML/ha</td>
<td>tc/ha</td>
<td>$/ha</td>
<td>$ 30ha 70ha</td>
</tr>
<tr>
<td>Dry Land</td>
<td>53</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>168</td>
<td>95</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>130.5</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>130.5</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>130.5</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>600</td>
<td>130.5</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>700</td>
<td>130.5</td>
<td>200</td>
</tr>
</tbody>
</table>

Assumes Sugar Price $200/tonne sugar - Harvesting and levies $6.50 tcane - Other variable costs $585/ha
Lodging and irrigation

- Lodging limits yield up to 25%
- Does it reduce need for irrigation?
- Can we keep crops erect by limiting irrigation?

---

### Kalamia experiment April 2001/July 2002
Total rainfall 728 mm

<table>
<thead>
<tr>
<th>Treatment</th>
<th>2 ML/ha</th>
<th>4 ML/ha</th>
<th>6 ML/ha</th>
<th>8 ML/ha</th>
<th>10 ML/ha</th>
<th>Full</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation applied (mm)</td>
<td>200</td>
<td>401</td>
<td>601</td>
<td>800</td>
<td>942</td>
<td>993</td>
</tr>
</tbody>
</table>

---

### Kalamia experiment July 2002/ August 2003
Total rainfall 557 mm

<table>
<thead>
<tr>
<th>Treatment</th>
<th>2 ML/ha</th>
<th>4 ML/ha</th>
<th>6 ML/ha</th>
<th>8 ML/ha</th>
<th>10 ML/ha</th>
<th>Full</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation applied (mm)</td>
<td>200</td>
<td>399</td>
<td>602</td>
<td>800</td>
<td>1000</td>
<td>1079</td>
</tr>
</tbody>
</table>
**Implications**

- Lodging limits the yield response to irrigation
- Delay lodging by limiting crop size till after wet?
- Could save a lot of water, cost and labour
Irrigation and the Burdekin Delta Aquifer
CSIRO/BSES

How much water and fertiliser is draining beneath the cane and can we manage better?

Irrigation Application in the Burdekin Delta

0 5 10 15 20 25 30 35 40
Site

Irrigation (ML/ha)

2000/1
2001/2
2002/3

0 5 10 15 20 25 30 35 40
Site

Nitrate-Nitrogen mg/L

N in Irrigation Water

70% of Recommended Application (220 kg/ha)

ANZECC Guideline

0 2 4 6 8 10
Site

N loss below Rootzone

Conventional
Improved Management

Way forward . . .

- Inefficient irrigation is costing money and has -ve effect on aquifer
- Improved irrigation management can improve WUE and decrease fertiliser leaching
- Delta traditionally has minimal drivers to improve WUE
- The Water Reform agenda will provide a huge driver
- Opportunity now to incorporate best tools available into well tested packages to ease the transition
INTEGRATED SPATIAL MANAGEMENT SYSTEMS FOR SUGAR CANE

Factors and management tools influencing cane production

Management Tools Available to Influence cane yield

- Soil testing
- Tissue testing
- Nutrient programmes
- Yield maps
- Soil type maps
- Weed pathogen ID
- Chemical application timing
- Chemical selection
- Equipment calibration
- Chemical/Nutrient audits
- Trash/burn options
- Follow management
- Legume break crops
- Irrigation scheduling
- Laser and subsurface drainage
- Cane varieties
- Cultivation practices
- Controlled traffic/row spacing

Factors Affecting Cane Growth

- Temperature
- Rainfall
- Cloud cover
- Drought
- Waterlogging
- Monoculture
- Compaction
- Cane nutrition
- Fert placement
- Surface drainage
- Subsurface drainage
- Mineralisation
- Soilborne diseases
- Diseases other
- Phytotoxicity
- Cane varieties
- Environmental pressure
- Weed competition
- Pests

VARIABILITY IN SOYBEAN FALLOW CROP

VARIABILITY IN CANE GROWTH

VARIABILITY IN CANE YIELD – SATELLITE IMAGERY

MANAGING VARIABILITY – IDENTIFYING SPATIAL DIFFERENCES
ELECTROMAGNETIC SOIL MAPPING TECHNOLOGY

Coulters measure drop in voltage.
2 x EC arrays – 0-30 cm and 0-90 cm
Logs changes in soil water holding capacity
Close correlation to cation exchange capacity
Close correlation to soil texture
Thermatic maps are geo referenced
Mapping represents a one time investment.

EM MAPPING – GEO REFERENCING OF SPATIAL DIFFERENCES

ZONE CREATION AND ATTRIBUTE IDENTIFICATION

GEO REFERENCED MANAGEMENT AND YIELD POTENTIAL ZONES FACILITATE A NUMBER OF ENVIRONMENTAL AND ECONOMICAL OUTCOMES
1. NUTRIENT INPUTS PEGGED TO YIELD POTENTIAL – VARIABLE RATE APPLICATION.
2. POSITIONING OF SOIL MOISTURE MEASURING INSTRUMENTS.
3. IRRIGATION SCHEDULING DETERMINED BY REFERENCED SOIL TYPE ZONES AND YIELD POTENTIAL.
4. VARIABLE RATE IRRIGATION TECHNOLOGY IS BEING ADOPTED IN THE USA.
5. MANIPULATION OF NUTRIENT INPUTS IF NITROGEN AND PHOSPHORUS CAPPING LEGISLATION IS INTRODUCED.
6. NUTRIENT MONITORING WITH REVISITING OF GEO REFERENCED SOIL TEST SITES.
7. CANE VARIETY CHOICE DETERMINED BY SOIL TYPE AND ZONE YIELD POTENTIAL.
8. HERBICIDE CHOICE DETERMINED BY ZONE ATTRIBUTES.
9. IDENTIFICATION OF HIGH RISK DISEASE ZONES.
10. SELECTION OF RESEARCH TRIAL SITES.

A TECHNOLOGICALLY SOUND SPATIAL PLATFORM ENABLES THE RECOGNITION AND SUBSEQUENT MANAGEMENT OF IDENTIFIED OBSTACLES IN PRODUCTION SYSTEMS.
Irrigation Application Survey of Mackay cane growers

Aims
1. To establish the amount of irrigation water applied by each irrigation.
2. Determine if the amount applied was the intended application rate.
3. Make contact with the irrigators of the area to create opportunities of working with them on irrigation issues in the future.
4. Benchmark irrigation efficiency

Method
• Over head irrigation
  – Discuss intended application rate with grower
  – Install 6 catch cans (3 each side of the tow path in row 8, 16 and 24)
  – Measure the amount applied the following morning

Method
• Furrow irrigation
  – Discuss intended application rate with grower
  – Calculate the amount applied by measuring the inflow rate, row length and width

Results
• 74 irrigation events were measured
  – 7 low pressure boom irrigators
  – 11 furrow irrigations
  – 10 hand shift spray lines
  – 17 hard hose irrigators
  – 2 pivot irrigators
  – 27 soft hose irrigators

Low pressure boom irrigators
• Application
  – Average 57mm
  – Range 45 – 65mm
• Target
  – Average 44mm
  – Range 32 – 50mm
**Furrow irrigation**

- **Application**
  - Average 122mm
  - Range 32 – 208mm
- **Target**
  - Only one grower was willing to give a target application rate
  - “put the water on until it gets to the end”

**Hand shift spray line**

- **Application**
  - Average 57mm
  - Range 31 – 80mm
- **Target**
  - Average 44mm
  - Range 25 – 70mm

**Hard hose irrigators**

- **Application**
  - Average 51mm
  - Range 31 – 77mm
- **Target**
  - Average 53mm
  - Range 30 – 70mm
Hard hose irrigators

- Intended application
- Actual applied

<table>
<thead>
<tr>
<th>Growers</th>
<th>Intended Application (mm)</th>
<th>Actual Applied (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
<td>42</td>
</tr>
<tr>
<td>2</td>
<td>44</td>
<td>46</td>
</tr>
<tr>
<td>3</td>
<td>48</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
<td>52</td>
<td>54</td>
</tr>
<tr>
<td>5</td>
<td>56</td>
<td>58</td>
</tr>
<tr>
<td>6</td>
<td>60</td>
<td>62</td>
</tr>
<tr>
<td>7</td>
<td>64</td>
<td>66</td>
</tr>
<tr>
<td>8</td>
<td>68</td>
<td>70</td>
</tr>
<tr>
<td>9</td>
<td>72</td>
<td>74</td>
</tr>
<tr>
<td>10</td>
<td>76</td>
<td>78</td>
</tr>
</tbody>
</table>

Soft hose irrigators

- Application
  - Average 44mm
  - Range 27 - 72mm
- Target
  - Average 44mm
  - Range 25 - 63mm

Conclusions

- Growers have a range of irrigation knowledge
- Application rate generally met soil water holding capacities
- Furrow irrigators had less knowledge of application rates (area that needs work)
- Growers are willing to adjust rates
- Catch cans set up under an overhead head irrigation system can be a very powerful tool to change irrigation practices
- “if you can’t measure it you can’t manage it”
Irrigation is essential for sugarcane production in the MDIA.

Sugarcane irrigation requirements

<table>
<thead>
<tr>
<th>District</th>
<th>Annual crop water use (mm)</th>
<th>Effective rainfall (mm)</th>
<th>Irrigation requirement (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mareeba</td>
<td>1550</td>
<td>405</td>
<td>1145</td>
</tr>
<tr>
<td>Dimbulah</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atherton</td>
<td>1170</td>
<td>760</td>
<td>410</td>
</tr>
<tr>
<td>Bundaberg</td>
<td>1360</td>
<td>580</td>
<td>780</td>
</tr>
</tbody>
</table>

Adapted from Table III of “Variation in the effectiveness of rainfall meeting crop water requirements in the Australian Sugar Industry” by Robertson and Muchow, 1997, ASSCT Proceedings.

Large annual rainfall variation

Total annual rainfall per crop year (July to June)

Irrigation requirement higher for 2002 & 2003

Estimated monthly irrigation requirement after rainfall

Irrigation drives productivity

Temporal changes in soil moisture – Q174 ratoons
Improved irrigation scheduling promoted flowering

Cumulative growth of Q174 ratoons
Arriga Rd, Arriga

Increasing scheduling frequency did not improve yields from furrow irrigation on heavy clay

<table>
<thead>
<tr>
<th>Irrigation Schedule</th>
<th>Irrigation (ML/ha)</th>
<th>TCPH</th>
<th>CCS</th>
<th>TSPH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grower minipan/75 mm deficit</td>
<td>7.1</td>
<td>120.7</td>
<td>16.74</td>
<td>21.09</td>
</tr>
<tr>
<td>BSES EnviroSCAN/50 mm deficit</td>
<td>7.9</td>
<td>120.8</td>
<td>16.7</td>
<td>20.18</td>
</tr>
</tbody>
</table>

Cumulative growth of Q172 plant
Dimbulah Rd, Arriga

Overhead irrigation trial
Rocky Ck, Tolga

Irrigation improved ccs in 2002

Rainfed Irrigation

IRRIGATION (mm)

SUCROSE ACCUMULATION OF Q120 RATOONS (CLEAN WHOLE STALKS)
Irrigation depressed ccs in 2003

Sucrose Accumulation of Q120 Ratoons
(Clean Whole Stalks)

\[ y = -0.0284x^2 + 1.0985x + 6.199 \]
\[ R^2 = 0.9222 \]

\[ y = -0.0176x^2 + 0.8619x + 6.8782 \]
\[ R^2 = 0.9456 \]

Profitability enhanced by mild water stress

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Irrig (ML/ha)</th>
<th>TPH (t/ML)</th>
<th>CRI (t/ML)</th>
<th>Mill ccs</th>
<th>TSPH (ML/ha)</th>
<th>Gain ($/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfed</td>
<td>0.7</td>
<td>72.6</td>
<td>-</td>
<td>14.9</td>
<td>10.8</td>
<td>1149</td>
</tr>
<tr>
<td>35mm deficit</td>
<td>5.15</td>
<td>107.8</td>
<td>7.9</td>
<td>13.5</td>
<td>14.6</td>
<td>1190</td>
</tr>
<tr>
<td>70mm deficit</td>
<td>2.53</td>
<td>198.6</td>
<td>14.2</td>
<td>13.7</td>
<td>13.5</td>
<td>1235</td>
</tr>
</tbody>
</table>

*Sugar Price = $235/t, Harvest/Transport & Levies = $7.34/t, Water Cost = $32/ML, Pumping Cost = $16/ML
Furrow Irrigating beds in Sugarcane

Presented by John Turner

Common Issues when Irrigating wide beds

1. Are wide beds more water efficient?
2. Do they take longer to irrigate?
3. Will the whole bed wet-up?

1. Are wide beds more water efficient?

- Less water per hectare is applied per irrigation
- Greater water demand due to increased planting density
- Increased root mass reduces deep drainage
- More frequent irrigations
- Well suited to supplementary irrigation regions

2. Do they take longer to irrigate?

- No measurable difference was detected
  - CTF produces compacted furrows
  - Crusting soils poor infiltration exacerbated
- Maintaining optimum growth requires more frequent irrigations

3. Will the whole bed wet-up?

- Bare soil or Trash Blanketed
- Soil type (surface sealing)
- Hydraulic properties (flow rate, wetting period, water quality, surge)
- Block slope
- Bed profile (height, slope)
- "Does the whole bed need to be wet?"

Furrow irrigation wetting profile in 2.1m beds (data collected by EnviroScan)
2.0m beds with 2-rows @ 800mm

Simple tool great effect

Spray Line wetting profile in 2.1m beds
(data collected by EnviroScan)

10cm
20cm
30cm
50cm
70cm
90cm

12:00 24:00
**Australian Cotton Industry**

Graham Harris  
Senior Development Extension Officer (Irrigation)

Sugar Industry Irrigation Workshop, 4 March 2004

- 70% of cotton is produced in NSW  
- Remainder grown in Queensland  
- Prior to the drought production was around 3 million bales per year  
- Australia is the third largest exporter (94% of crop exported)  
- There are around 1500 growers, the majority as family run farms

**Irrigation facts**

- In 1999-2000 cotton was grown on 18% of the irrigated cropping area in Australia (sugar on 9% and pastures on 40% of the 2.26 million ha irrigated)  
- 80% of cotton crop is irrigated  
- Surface irrigation used on 87% of irrigated crop

**Irrigation method for cotton**

<table>
<thead>
<tr>
<th>Method</th>
<th>% of cotton grown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Furrow siphons</td>
<td>86</td>
</tr>
<tr>
<td>Furrow lay-flat</td>
<td>1</td>
</tr>
<tr>
<td>Pivot</td>
<td>7</td>
</tr>
<tr>
<td>Lateral</td>
<td>4</td>
</tr>
<tr>
<td>SDI</td>
<td>1</td>
</tr>
</tbody>
</table>
Water Requirement

<table>
<thead>
<tr>
<th>Centre</th>
<th>Water Requirement (ML/ha)</th>
<th>Range</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dalby</td>
<td></td>
<td>2.0 to 7.1</td>
<td>4.3</td>
</tr>
<tr>
<td>Emerald</td>
<td></td>
<td>0 to 5.0</td>
<td>3.2</td>
</tr>
<tr>
<td>Goondiwindi</td>
<td></td>
<td>2.2 to 8.0</td>
<td>5.1</td>
</tr>
<tr>
<td>Hillston</td>
<td></td>
<td>4.6 to 9.0</td>
<td>7.1</td>
</tr>
<tr>
<td>Moree</td>
<td></td>
<td>2.5 to 8.6</td>
<td>5.4</td>
</tr>
<tr>
<td>Narrabri</td>
<td></td>
<td>2.4 to 8.7</td>
<td>5.4</td>
</tr>
<tr>
<td>St George</td>
<td></td>
<td>1.0 to 6.9</td>
<td>4.3</td>
</tr>
<tr>
<td>Theodore</td>
<td></td>
<td>0.6 to 5.6</td>
<td>3.5</td>
</tr>
<tr>
<td>Trangie</td>
<td></td>
<td>2.9 to 8.8</td>
<td>6.3</td>
</tr>
</tbody>
</table>

Source: Ozcot for 1997 to 2001

WUE Indices

- Australia – 227 kg lint/ML
- California – 138 kg lint/ML
- Egypt – 136 kg lint/ML
- Pakistan – 59 kg lint/ML

Adopting BMP in the Cotton Industry: research to practice

Graham Harris
Senior Development Extension Officer (Irrigation), DPI&F/Cotton CRC
Sugar Industry Irrigation Workshop, 4 March 2004

Cotton BMP program goals

- Participants committed to improving farm management practices
- Participants have developed and follow policies and farm management plans that minimise the risk of any adverse impacts on the environment or human health
- Credible demonstration to the community of stewardship in the management of natural resources and farming operations
Cotton BMP program elements
• A voluntary continuous improvement process designed to assist growers improve their farm management practices
• The key elements are:
  1. BMP booklets that outline growers’ legal responsibilities and recommended practices to help meet these

2. Self-assessment worksheets to assess risk, and help growers assess their own operations against recommended best practices
3. Action plans developed and implemented to address issues identified through self-assessment
4. Voluntary audit of growers implementation of BMP – this provides recognition of work done and advice on areas for further improvement
5. Continued review and assessment of their farming operations

BMP Manual Components
• Application of pesticides
• Storage and handling of pesticides
• Integrated pest management
• Farm design and management
• Farm hygiene
• Risk Assessment
• Petrochemical Storage & handling
• Land & Water Management (draft)
• Managing cotton farm safety course (not BMP because of auditing complexity)

Results to date
• 95% of growers have been introduced to BMP
• 85% of growers have changed practices as a result of the BMP program
• 35% of growers have been audited (representing 60% of area)

Reasons for success
• Industry lead voluntary program
• BMP content based on best possible research
• Significant extension effort by Cotton Australia general service managers (located in cotton districts and providing one-on-one and area wide group support, at a cost of $700,000 p.a.)
**Cotton BMP benefits**

- Improved farm management
- Assisting compliance with legal obligations
- Sustainable agricultural practices that ensure the longevity of farms and the cotton industry
- Improved environmental performance
- Enhanced reputation of the industry in the community

**Future direction for BMP**

- Cotton Australia and CRDC funded by NHT to participate in a national Environmental Management System Pilot Program
- Steering Committee comprising CA, CRDC, ACGRA and WWF has been established
- Independent evaluation of BMP impacts
- BMP Land and Water Module developed (currently being tested)

**Objectives**

- Provision of technical support for implementation of Cotton BMP Land & Water Management Module
- Build capacity amongst cotton and grain farming system service providers to deliver irrigation services

**RWUE II**

**Cotton and Grain Irrigated Farming Systems**

Graham Harris
Senior Development Extension Officer (Irrigation)

Sugar Industry Irrigation Workshop, 4 March 2004
Inputs
- $703,900 (2 years)
- 3.5 extension & adoption staff
- Training expertise contracted
- RWUE 1 experience and knowledge
- Irrigation knowledge mapping from NPSI Knowledge Management Project

Outputs
- 70% grower involvement in RWUE II
- 30% grower participation in BMP
- 10% of growers audited for BMP

Outcomes
- Contribute to WUE targets set by catchment groups
- Contribute to relevant environmental targets of catchment groups
- Comprehensive irrigation consulting services in all regions
- Increased grower and consultant understanding of water management

Impacts
- Increased cotton production per ML
- Avoid contaminated runoff into rivers and streams
- Manage deep drainage – reduced salinity risk

Manage deep drainage through precision irrigation.
Adoption of best practices for irrigation and drainage.
Reducing irrigation by exploiting soil water
• Kalamia dry-down trial
• Kalamia ET0 scheduling trial
• Childers scheduling trial

Autumn/Winter on Nov ratoon
Sucrose Yield (t/ha)

Testing crop coefficients in the Burdekin
Plant crop, 27 Sep 2000 to 25 Sep 2001, Q96, Total rain = 793 mm

<table>
<thead>
<tr>
<th>Treatment</th>
<th>1.0*ET0</th>
<th>1.25*ET0</th>
<th>1.4*ET0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation (mm)</td>
<td>349</td>
<td>508</td>
<td>671</td>
</tr>
<tr>
<td>Cane yield (t/ha)</td>
<td>141</td>
<td>142</td>
<td>137</td>
</tr>
<tr>
<td>Sucrose yield (g/m2)</td>
<td>20.3</td>
<td>21.1</td>
<td>20.1</td>
</tr>
</tbody>
</table>

Scheduling trial at Childers (Graham Webb)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rainfed</th>
<th>Capped</th>
<th>Plus</th>
<th>Grower</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006/2001</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net irrigation (ML/ha)</td>
<td>0.7</td>
<td>1.81</td>
<td>3.08</td>
<td>3.33</td>
</tr>
<tr>
<td>Cane yield (t/ha)</td>
<td>108</td>
<td>119</td>
<td>123</td>
<td>119</td>
</tr>
<tr>
<td>Sucrose yield (t/ha)</td>
<td>13.9</td>
<td>14.8</td>
<td>14.6</td>
<td>14.9</td>
</tr>
<tr>
<td>2001/2002</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net irrigation (ML/ha)</td>
<td>0.5</td>
<td>2.58</td>
<td>3.61</td>
<td>4.54</td>
</tr>
<tr>
<td>Cane yield (t/ha)</td>
<td>102</td>
<td>93</td>
<td>107</td>
<td>100</td>
</tr>
<tr>
<td>Sucrose yield (t/ha)</td>
<td>15.7</td>
<td>14.0</td>
<td>16.8</td>
<td>15.4</td>
</tr>
<tr>
<td>Lodging angle (º)</td>
<td>35</td>
<td>63</td>
<td>85</td>
<td>88</td>
</tr>
</tbody>
</table>
Deep water extraction at Childers experiment 2002/2000
Rainfed treatment

Implications

- Irrigation after a big wet may not be necessary
- While crop requires 1.25 ET0, 1.00*ET0 is OK on a full profile (Spring/Summer)
- Response to irrigation in deep red soils may be low
- Plant available water capacity (PAWC) may be greater than we think
- Winter RAW>Summer RAW
Maximising Sugarcane Yield and WUE in Bundaberg (with Limited Water)

Craig Baillie

Background

Context
- Limited water (2 – 3 ML/Ha)
- Low sugar price

Focus (fine tune performance)
- Existing irrigation systems
- Irrigation practices

Looked at
- Improving irrigation system performance
  - winch and furrow (91% of systems in use)
- Maximising crop growth
  - starting after rainfall (irrigation rotation)

Key Finding

Greater opportunity to maximise yield through improvements to irrigation system performance than irrigation timing

Water Winch Improvement

- At winds speeds 10 – 15 km/h
- In row direction
  - use taper nozzles (increase CU by 16%)
- Across the row
  - not as critical (advise taper nozzles)
- Reduce gun arc angles to 240 – 270°
- Reduce lane spacings (55 - 65 m)
  - not practical
  - may not be needed by reducing gun arc angle
- Cease operation at wind speeds > 15 km/h

Furrow Improvement

- Furrow Flowrate
  - generally 1 L/s; up to 3 - 4 L/s high infiltration soils
  - (45 ⇒ 90%, 75 ⇒ 98% AE)
- Cutoff Time
  - as water arrives at the end or just before
- Banked ends
  - providing good drainage

High Infiltration Soils (other options)

- AFI - Alternate Furrow Irrigation
  - in combination with higher furrow flow
    - (45 ⇒ 95% AE)
- Cropping Practices
  - shallow cultivation to maintain compaction
    - (58 ⇒ 94% AE)

Yield Increase

![Graph showing the relationship between Christiansen's Uniformity Coefficient (CU%) and Percentage Reduction in Yield.](image)
**Irrigation Practices**

- System unable to keep up with crop demands (operating at deficit)
  - self scheduling
- Opportunity to fine tune practices
  - start up after rain.

**Improving Irrigation Practices**

- Modelling (APSIM)
  - best irrigation strategy varied from season to season
  - flexibility due to small amount of water relative to crops
  - total demands
  - reflected by similar effective rainfall between different start
  up strategies
  - simulated yield differences were less than 5 TC/Ha

**Improving practices cont ...**

- Use all of the available water
- Starting earlier
  - provided greater opportunity to use all water
  - provided opportunity to use additional announced allocation.
- Starting later
  - didn’t use all of the available water in 30% of years (3 ML/ha)
  - less risk ?? - less opportunity
- Interaction between irrigation start up and seasonal use.
  - 1st irrigation and last irrigation were separated by 1 month

**Take Home Message**

In the context outlined

- Use all of the available water
  - risk of being too conservative
- Maximise the potential by applying it well
  - significant opportunities identified
  - focus on maximising system performance
Shallow Water Table Contributions to Sugarcane Production

Impacts on irrigation
- Upflow from fresh, shallow water tables contributes significant amounts of water in many cropping systems.
- Experiments show this happens in sugarcane too.
- How can we use irrigation water more efficiently where a shallow water table occurs?

Location, Location, Location...
- Ingham through to Mossman
- Donlen and Poplar soils in Biboohrah area
- Cattle Ck Catchment
- Leichardt downs
- Glen Isla area
- Hamilton plains
- Proserpine delta
- Koolachu
- Sands closer to coast
- Drainage lines
- Duplex soils of alluvial plains south of the Pioneer River
- Isis district
- Moore Park
- Tantitha
- Nambour
- Rocky Point
- Pimpana

Pick the rainfed treatment?

Impact of irrigation response

How do you know what to do?
Irrigation Time savers

Trevor Willcox

Cane growing is moving in two directions

1. Small farms with owners working off-farm
2. Or large farms with little ability to employ labour

Either way cane growers are looking for ideas to reduce the time spent irrigating e.g:

• Centre pivot or lateral move irrigators
• Tailwater return
• Auto shut-down and start-up devices
• Techniques for reducing time spent shifting traveling boom or water winch irrigators.

Time saving devices will help growers maintain irrigation schedules and productivity
Time (labour) will be a major consideration by growers and must be considered in future R&D needs.

Workshop session

• What technology is available that could reduce the time input to irrigation?
**Performance Evaluation for Surface Irrigation**

**IN-FIELD MEASUREMENT**
- inflow, advance, outflow metering, communication software

**COMPUTATIONAL SOFTWARE (INFILT & SIRMOD)**
- computation of infiltration parameters
- simulation of surface irrigation hydraulics
- evaluation of surface irrigation performance
- volume balance field design capabilities

**SERVICE DELIVERY SYSTEM**
Commercial agencies; extension/research organisations; Training programs

---

**Why Irrimate??**

- Identify if deep drainage is occurring;
- Calculate the volume of tailwater run-off;
- Evaluate effect of different flow rates and cut-off times;
- Provides efficiency and uniformity measures to evaluate where areas of fields are being under/over irrigated;
- Evaluation of field conversion/layout options and assist in the calculation of tailwater system capacities

⇒ Improve irrigation water use efficiency

---

**Precision Surface Irrigation**

"Monitor to manage better"

- Up to ~15% increase in application efficiency
- May reduce irrigation waterlogging increasing yield

Common solutions:
Flow rate, pull-time, field length, furrow management

---

**NCEA Objectives**

Address community and industry requirements to improve natural resource management

- Develop a sustainable system for surface irrigation evaluation. “Tool of Choice”
- Training to researchers, extension staff and commercial service providers
- Commercial delivery mechanism to farmers
- Ongoing research and development
- Brand name that represents quality and best practice.

---

**Business Model**
Conclusions

- There is a growing market for irrigation efficiency services.
- Driven by RWUEI, WAMP, Water pricing and policy, Economic performance of producers
- Services include Training, Measuring equipment, Computing Tools
- Challenge to develop sustainable delivery mechanisms
Trickle Irrigation

Opportunity to apply the right amount in the right place at the right time

Soil Root Zone

Groundwater (quality)

Drainage quantity/quality

Surface or buried drip

Soil type

Crop

Trash

A. Furrow irrigation

B. Overhead irrigation or rainfall

C. Trickle irrigation

D. Influence of a shallow water table

In all cases, rainfall moves salt downwards, and evaporation moves salt upwards. A net concentration of salt in the root zone must be avoided.

Salt distribution in soils

Evaporation

Salt concentrates at depth

Rainfall or irrigation

Salt concentrates at edge of wetted zone

Water and salt movement

Evaporation

Salt concentrates at surface

Water and salt movement

Water application in sand

Change in water content

Water applied for first 5 h then followed by redistribution

Strategy A

Fertigation applied at end of irrigation event

Sand

Change in solute concentration

Strategy B

Fertigation applied at beginning of fertigation event

Sand

Change in solute concentration
**Nitrogen management**

- Little evidence of improved N management in fertigated sugarcane, BUT ... evidence that N applications can be reduced
- Inputs exceed output at higher N application rates
- High localised soil water contents promotes mineralisation of soil organic matter and N losses

**Key Issues**

- Economics
- Must design and manage to meet soil and crop requirements (tools such as WetUp ....)
- Requires increased level of management
- Manage fate of water, salt, nutrient (N), agrochemicals (need net downward movement of salt – "LF")

**Fertigation strategies**

- **Strategy A**
  - Start water
  - End water
  - Start solute
  - End solute
  - Time (h)

- **Strategy B**
  - Start water
  - End water
  - Start solute
  - End solute
  - Time (h)
NPSI Knowledge Management
Sugar Industry Questions
4 March 2004

Question 1

• Overall, how would you view innovation and learning amongst sugar producers?
  – How is knowledge built?
  – What are the attitudes towards change?

Question 2

• What are the key issues in water management in the sugar industry?

Question 3

• What do you see as the public/private sector roles in the sugar industry?
  – In relation to water?

Knowledge Management in Cotton & Grain Irrigation

• Refer to the two pager outlining the results of the project to date.

Question 4

• Is there anything that surprises you about these points or anything that you think might be different in the sugar industry?
Question 5

- Based on this, what are the key similarities and differences between cotton/grains and the sugar industry?
  - Are there key people/resources that you use in sugar that we are missing/not valuing?
  - Are there any of our people/resources that you think might work in sugar?
- Roles of the different sectors
Appendix 13
Implications of recent SRDC funded irrigation R&D

Notes from Irrigation workshop held at BSES Mackay 5/5/06 (9am to 3pm)

Present: Dollat (RWUE); Shay (BSES); Joe Muscat (BSES, Grower); George Jackson (BSES); Gerry (BSES); Phil (MAPS); Burn Ashburner (MAPS); Rob Sluggett (BSES); Brad Hussey (BSES); Steve Attard and Geoff Bamber (CSIRO)

The meeting was started by Rob Cocco (BSES Area manager, Mackay) who left early. The general response was very positive and everyone expressed an appreciation for the effort we took to come to Mackay to present the results of our research. Ian Wallace (BSES, CEO) also thanked us for this effort.

Agenda

- Background
- Unlimited water (see Appendix x)
  - Theory
  - Trial results
  - Demo of WaterSense (unlimited)
- Limited water (see Appendix x)
  - Theory
  - Demo of WaterSense (Limited)
- Future of these services/tools
- Opportunities for BSES to implement these and other tools derived from SRDC funded irrigation research

Comments from participants

Rob Cocco would like the main outcome of the workshop to be ideas for new irrigation projects

Joe Muscat would like to see WaterSense paddocks to be grouped by these options:
  - Rain gauge (as is now)
  - Pump
  - Farm
  - Irrigator
  - Valve

Some of these groupings may be identical (i.e. one Pump, one rain gauge, n paddocks)

Burn: Is it possible to present rainfall compared to average rainfall to help explain why WaterSense (limited) forecasts irrigation on certain dates? We suggested monthly rainfall would be appropriate, not daily rainfall. All agreed that simplicity should be favoured over information overload.

Joe asked about the capability to assess the value of additional irrigations. We explained that WaterSense could cope with a limited number of whatif scenarios midstream (i.e. Growers could increase the allocation during an update to see what would happen to the yield and the schedule). If the question was about longer term responses to increased allocation then long-term water production functions (WP) would be more appropriate.
We demonstrated the Pivot charts that were done some years ago and these were considered to be highly valued.

Future actions and projects
Dameasy: There was a lot of discussion about Dameasy type capability and everyone agreed that this was urgently required for Mackay. We explained that many groups (even in other industries) acknowledged this but no one has committed funds to developing this capacity for the issue they regard as so important.

Brad indicated that BSES Mackay had 0.38 FTE funded for irrigation R&D. This includes the 0.12 FTE for the Tony Linedale’s new project. We discussed how best to use the 0.38FTE. This is a matter for BSES however. There was strong support for some targeted workshops to share the material discussed at this workshop with people who could help to implement it (WaterSense, WP, Dameasy type technologies) in Mackay with the ultimate aim of ‘getting more’ and ‘using it better’, to coin Brads terms.

Final comments
Joe said this was excellent information and he for one is keen to use the model (we later discussed how we could make this happen, starting with WaterSense – limited as for Sarina growers).

Dollet felt that we had filled a gap in irrigation technology

Phil. Asked if we should focus on a small number of growers who might readily understand and adopt this technology. Most growers do not think about scheduling.