Implementation of irrigation practices for profitable resource efficient sugarcane production in the Ord
Implementation of irrigation practices for profitable resource efficient sugarcane production in the Ord

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EXECUTIVE SUMMARY

Sugarcane is currently the major crop in the Ord River Irrigation Area (ORIA) in terms of area, occupying approximately 4000 hectares or a third of the irrigable area. It is also possible that further expansion could occur soon within the Ord Stage 2 area. The new industry is continuing to develop guidelines for and to initiate implementation of best management practice, to ensure the development of a profitable and sustainable industry. This project contributed to the provision of an extension service which is critical in assisting the industry in this development. Irrigation water application in excess of 30 ML ha\(^{-1}\) yr\(^{-1}\) was common commercial practice when sugarcane production commenced in 1995. High irrigation application not only impacted on profitability but also contributed to rising water tables and land degradation. Consequently this project aimed to build capacity in the community to save water and labour and to reduce rising water tables.

The APSIM-Sugarcane model (Keating et al., 1999) enabled the initial testing of scientific hypotheses of sugarcane production in the Ord. During the previous SRDC project (CSR022) certain adjustments were required for APSIM simulations under Ord conditions but these were not entirely satisfactory. In CSE007 it was necessary to introduce growers to a framework based on the Penman-Monteith (PM) equation. This framework is concerned mainly with daily crop evapotranspiration (ET\(_C\)) for which it is more suited than APSIM-Sugarcane but does not consider much detail on crop physiology or soil physics. A number of experiments were conducted to improve both the APSIM and PM frameworks for a better working knowledge of the soil-plant-atmosphere continuum in the Ord.

From the APSIM based scheduling experiments we concluded that a 50% soil water deficit represented the lower limit of readily available water (RAW). It was then possible to derive RAW values (56 to 68 mm) for the major soil types in the Ord in the interests of balancing requirements for high sugar yields and reduced water use. Lodging rules introduced to APSIM for conditions in the east were able to explain a ‘slow-down’ phenomenon noted repeatedly in earlier experiments after about 30 t ha\(^{-1}\) biomass had been produced. More recently an early ratoon crop accumulated biomass rapidly up to 55 t ha\(^{-1}\) before slowing down. While the slow down was triggered by a combination of crop mass, soil water content and storm rainfall the physiology of the slow growth process remains unresolved.

The project made extensive use of a Bowen ratio energy balance (BREB) system which measures energy being used to evaporate water from the crop and soil (ET\(_C\)). Daily water use in the Ord seldom exceeded 8 mm d\(^{-1}\) compared to original estimates from APSIM of more than 12 mm d\(^{-1}\). Annual net irrigation requirement based on the PM framework was 670 to 1628 mm and these estimates have been used to assess water requirements for sugarcane production in Ord stage 2.

The recent establishment of irrigated sugarcane in the Ord offered a chance to try new concepts of participatory action research (PAR). The end result of the PAR process was ‘WaterBalance’, a computer program which growers adopted readily as a scheduling tool as a result of their involvement in its development. In January 2006, three Ord growers were actively using the prototype WaterBalance to schedule their irrigations. These growers had a total of 22 blocks on the system. A fourth grower obtained weekly updates on the current scheduling interval via fax or email. WaterBalance was later superseded by WaterSense which combined WaterBalance with an earlier web-based irrigation tool for growers using limited water in the Bundaberg/Isis region. One Ord grower continues to use WaterBalance while the others have switched to WaterSense which has now been endorsed by the BSES Limited and the Cooperative Research Centre for Irrigation Futures. In all regions adoption by those growers familiar with the background research has been immediate. Indications are that the combined use of the Internet, PAR and concurrent research and demonstration will open the way for the adoption of research findings in the management of irrigation and possibly other aspects of sugarcane farming.

Evaluation surveys were conducted in 2003, 2004 and 2006 to assess perceptions and practices about irrigation and how these were influenced by the project. The 2004 and 2006 surveys in particular indicated how much irrigation practices had changed since the initial benchmarking survey was conducted by Wood et al (1998). This original survey reported an average water application per crop of 40 ML ha\(^{-1}\) and by 2006 growers reported an average use of nearly half this amount.
The project was rated second only to rain by growers in influencing their irrigation management decisions. By 2006 an increased number of growers had taken action to minimise their potential impact on groundwater. It is reasonable to expect that the benefits from CSE007 will be transferred to irrigated sugarcane regions in the east through the adoption of WaterSense.

BACKGROUND

Sugarcane is currently the major crop in the Ord River Irrigation Area (ORIA), occupying approximately 4000 hectares or a third of the irrigable area. It is also possible that further expansion could occur within the Ord Stage 2 area, at a later stage.

The Ord industry was established with the commissioning of the sugar mill in late 1995. The new industry is continuing to develop guidelines for and to initiate implementation of best management practice, to ensure the development of a profitable and sustainable industry. Provision of an extension service is critical in assisting the industry in this development. This requirement was initially supported by the SRDC, the Ord industry, including both miller and growers, and Department Agriculture Western Australia (DAWA) with funding for an extension service provided to engage Mr Ian Freshwater who visited the Ord at regular intervals from 1995 to 1997. An extension agronomist, Mr Jim Engelke was then appointed on a full time basis in 1998, to continue this work. Jim resigned in 2002 and was replaced by Mr Bill Webb a highly experienced extension officer from Proserpine. Funds were sought from SDRC through a new project (CSE007) to support the extension service for another four years in partnership with the Ord industry and Agriculture Western Australia, each meeting one third of the cost.

Irrigation water application in excess of 30 ML ha⁻¹ yr⁻¹ was common commercial practice when sugarcane production commenced in the Ord Irrigation Area in 1995. High irrigation application not only impacted on profitability but also contributed to rising water tables and land degradation. It was perceived that climatic conditions dictated a high water requirement for sugarcane growing in the Ord (Robertson et al., 1997) and farmers faced a considerable challenge in meeting that requirement whilst maximising profitability and minimising drainage losses and potential impacts on the groundwater and environment. Wood et al., (1998) conducted a survey to benchmark irrigation practice which showed that average water applied per annum was 32.5 ML ha⁻¹, with values ranging from 15.3 to 53.8 ML ha⁻¹. The development of irrigation practice that maximises profitability and minimises groundwater accessions is a high priority for the Ord sugar industry.

Irrigation scheduling, soil water availability and drying off requirements were investigated in a SRDC irrigation research project (CSR022) completed in June 2001. Surprisingly, there was little response to drying-off periods as long as 80 days. Drying-off did not increase sucrose content (Pol) in cane. The highest sucrose yields were obtained by the most frequent irrigation regimes in all three scheduling experiments conducted in this project. Sucrose yield losses of 1.6 to 2.1 t ha⁻¹ (mostly non-significant) by irrigating less frequently were not large when considering the total amount of water saved (up to 8.8 ML ha⁻¹). The risk of substantial yield loss by irrigating at deficits greater than 123 mm would not justify the considerable further savings of irrigation. Irrigating when about 50 % of the plant available water capacity had been used appeared to be a reasonable compromise between maximizing sucrose yield and minimizing off-site impacts associated with irrigation particularly the impact of irrigation on rising ground water levels and on the quality and quantity of runoff returning to the river system. However, it was recommended that further research be conducted to understand the basis of these responses and their wider applicability across different seasons and soil types. Nevertheless, the potential existed for more sustainable irrigation practices.

The CSR022 study also provided information on the plant extractable soil water and pattern of water extraction with depth in the soil profile for a range of soil types in the ORIA. Four broad soil types across the Ivanhoe Plain were characterised. At the Central Ivanhoe site, 226 mm of water in a 2 m profile was available to the sugarcane plant. The plant extractable soil water in 2 m differed at the other sites with the Aquitaine, Northern Ivanhoe and the Southern Ivanhoe soils holding 187, 193 and 167 mm respectively. The depth of water extraction varied across sites with extraction occurring to 1.8 m at the Central and Northern Ivanhoe sites, 1.6 m at the Southern Ivanhoe site and to only 1.0 m at the Aquitaine site.

Knowledge of the extractable soil water and crop water requirements allowed a better understanding of the response of sugarcane to irrigation schedules for different soil types. The soil water characteristics information for these soil types in the ORIA was a prerequisite for the use of cropping system models to analyse the consequences of different
irrigation regimes to develop strategies for best-practice irrigation management that maximise profitability and irrigation efficiency.

The APSIM-Sugarcane model (Keating et al., 1999) was introduced to Ord growers at the outset of this research work since this was the theoretical framework used by the researchers who were conscious that generalisations from a few irrigation trials were possible only with such a framework. APSIM had been developed and tested against data from several countries (Keating et al., 1999; Cheeroo-Nayamuth et al., 2000; Inman-Bamber et al., 2001) and was found to account well for yield produced under high input conditions (Keating et al., 1999) as well as water limited condition (Inman-Bamber et al., 2001). However CSR022 showed that some APSIM settings used in Queensland were not appropriate for the Ord. Under Ord conditions, radiation use efficiency and hence crop water use had to be reduced after the crop had reached a certain biomass threshold (30 t ha⁻¹ or about 80 t ha⁻¹ of cane) in order to match simulated and measured crop water use and yield (Attard et al., 2003). Crop water use had to be reduced further by increasing transpiration use efficiency from 8.7 to 10.0 g kPa kg⁻¹.

Another SRDC project which was based largely in the Burdekin (SRDC CTA038) provided results that were similar in many ways to those obtained in the Ord, including low crop evaporation and no reduction in cane yield by withholding irrigation from April to October. The Burdekin approach was based on micrometeorological methods using the Bowen ratio energy balance and the Penman-Monteith equation. The new CSE007 project sought to transfer this technology to the Ord in order to establish sound physical reasons for the lower-than-expected water use in the Ord. The sustainability of the Ord irrigation scheme depends on the extent to which water supply to the roots can be matched with crop demand for water. The new project was to improve knowledge of the biophysics responsible for crop water demand in the Ord and to improve the modelling framework which was embodied in APSIM at the outset of the project. APSIM could then be used to develop sound irrigation scheduling guidelines in a manner that is appropriate for Ord irrigators. Given that the Ord sugar industry was relatively new the Ord irrigation scheme offered a chance to look at crop water use in sugarcane from scratch in a new and distinct environment using the latest science and technology in micro-meteorology and soil water monitoring. However this type of science was not the only concern of the project. It was particularly important to try new concepts for participatory action research (PAR). The R&D was closely linked to the extension effort and this report will attempt show how important this link was in developing appropriate new technology and achieving its adoption.

OBJECTIVES

The Ord community is well aware of their dependency on water in a sensitive ecosystem that has brought both prosperity and hardship in the past. An opportunity existed for building capacity in the community to save water and labour and to reduce rising water tables, following unexpected findings of recent SRDC research in the Ord. This project aimed to follow up on these findings and to implement improved irrigation management by:

A. Supporting an effective sugarcane extension service in the Ord which will:
   1. Identify all information needs for the whole production system including irrigation
   2. Obtain information in Australia and elsewhere for improved farm and mill performance
   3. Work with Ord canegrowers to disseminate information
   4. Obtain new knowledge through participatory R&D
   5. Share information with Australian sugar industry nation wide.

B. Conduct new research to:
   1. Confirm the new irrigation research findings in a wider range of soil types and seasons
   2. Improve irrigation guidelines from model analysis of yield, water use and economics
   3. Evaluate new guidelines with on-farm participatory R&D.
METHODOLOGY and ACHIEVEMENTS

These will be presented under the important outputs intended for the project at the outset. Methodologies and achievements for each output were closely related and will be presented separately for each output.

1. Benchmarks of irrigation practice for sugarcane production for evaluation of uptake of changed practices

Three evaluation surveys were conducted during the project to assess perceptions and practices about irrigation during the life of the project and how these were influenced by project outputs.

**August 2003 (Appendix 1)**

In August 2003 the Ord Irrigation Cooperative (OIC) and the Department of Agriculture Western Australia (DAWA) worked in partnership to survey 19 of OIC's customers to explore local growers' knowledge, perceptions and practices in relation to water management of the Ord River Irrigation Area (ORIA). The purpose of the survey (Appendix 1) was to provide data to contribute to the OIC's Water Use Improvement Program, to benchmark perceptions and practices for an irrigation extension project funded by the Sugar Research and Development Corporation (SRDC) and to DAWA's annual Farm Business Review. The survey of 19 OIC customers included a sub group of 8 cane growers. The following are the key results obtained from survey of this sub group.

- All survey participants stated that they thought it was important that environmental impacts caused by irrigation should be managed, and all stated that they were interested in changing their farm practices to help contribute to addressing these issues.

- Perceptions of crop water requirements, number of irrigations per season, and irrigation intervals were variable. The average of survey participants’ perceptions of current on-farm water use efficiency was 55%.

- All survey participants rated their knowledge of environmental issues and solutions as average or high, and the majority of survey participants rated their knowledge of locally relevant water management programs as average or low.

- The large majority of survey participants have taken part in a range of improved water management practices on their properties. The greatest limiting factor in preventing enhanced participation in these practices includes a lack of time and business inability to pay for changes on-farm.

- Field trips and targeted group training sessions were the communication media best supported by survey participants. Survey participants stated they would more likely respond to communication media if they are brief, relevant and if they suit their work schedules.

- Participants identified several issues as critical for the long term profitability of farm businesses in the ORIA. These were resources/environment, DAWA support, business operational issues and land availability. DAWA's role in addressing these issues was identified as communication with farmers, approach to research, increased knowledge and business/regional support.

- In regard to irrigation practice, growers surveyed said they used between 20 to 29 ML ha⁻¹ on average with 8 to 20 irrigations.

**July 2004 (Appendix 2)**

By July 2004 project CSE007 had been running in the Ord River Irrigation Area for two years. Since the project’s objective was to build capacity in the irrigating community to save water and to reduce rising water tables it was time to find out how this capacity had been influenced by the project. Survey questions were developed by Bill Webb with the help of a number of people including Tracy Henderson from SRDC. The survey contained 20 questions of which 8 were Yes/No questions, 7 were tick-a-box questions and the remainder interpretative questions. The survey was hand delivered to growers, most of whom opted to complete the survey immediately. Twelve growers/managers on 16 farms out of a total of 20 farms had the opportunity to participate in the survey. No selection process was employed. Growers were invited to participate on the basis of opportunity during Bill Webb's day to day activities.
The surveyed farms covered 95.4% of the total area under sugar cane in the ORIA (3 848 hectares surveyed out of 4 032 hectares under sugar cane). The range of the area of sugar managed by each survey respondent was 41 - 690 hectares with a mean of 380 and a median of 455 hectares.

Experience in years of growing sugarcane ranged from 2 to 44 years with a mean of 13.4 years which is greater than age of the Ord sugar industry showing that some growers have had previous experience with sugar cane growing in other areas.

**Results of 2004 survey (Appendix 2)**

Growers were well aware of the project and were keen to support it. Whilst some confusion had been generated in the past by research results, growers were aware that the R&D aspects of the project were making progress towards best practice irrigation management. Growers were also acutely aware of, and supportive of, the project through the extension activity funded by the project.

This survey indicated how much irrigation practices had changed since the initial benchmarking survey was conducted under project CSR022 (1996 to 2002). This original survey reported an average water application per crop of 40 ML (range 20 to 80 ML) per hectare with an average of 27 irrigations (range 15 to 42). The 2004 survey reported an average use of 21 ML ha⁻¹ (range 13 to 30 ML) with 16 irrigations (range 10 to 21). Total water use, number of irrigations, and timing of irrigations have been substantially and favourably modified according to this survey.

Growers made several recommendations for the project team to note for the remaining two years of the project. They asked the project team to further fine-tune tools for real-time scheduling of irrigations, and that as many communication methods as possible be employed to get this information to growers. Growers wanted to be guided by the Extension service to seek ways to minimise the off-site impact of irrigation by improving application efficiency. Commonly mentioned by growers was the fact that information on water use (volumes) was not readily available. OIC manager Andy Kelly was approached with the question. Andy maintains that the information is fed back to growers, but they chose not to apply the necessary analysis time to the data to minimise the off-site impact of irrigation by improving application efficiency.

**Final survey January 2006 (Appendix 3)**

The final survey in January 2006 was conducted in a manner similar to that of the 2004 survey. For the 2006 survey a number of questions related to irrigation best practice were added to the survey questionnaire which was otherwise the same as the one used in 2004. These questions were adapted from the Compass workbook and scored as in Compass (Appendix 3), so that some comparisons could be made with scores obtained from Compass participants in the Eastern states Sugar Industry.

The results of the final evaluation survey could be compared directly with a mid-term survey conducted in 2004 and indirectly with a benchmarking survey for this project conducted in 2003 and with the benchmarking survey for a previous project (CSR022) conducted in 1996. The most remarkable difference between the original survey in 1996 and the 2006 survey is a reduction of average water used per annum per hectare of sugarcane from about 33 ML ha⁻¹ yr⁻¹ to about 21 ML ha⁻¹ yr⁻¹. The average water actually used in 1996 was 40 ML ha⁻¹ because the industry was based largely on plant crops older than 12 months.

The majority of growers have accepted outcomes of the project and attitudes towards environmental issues associated with irrigation are positive. There has been growing user confidence in irrigation related advice offered.

In 2006 more growers claimed awareness of the project than in 2004, and more growers had become involved with the project since that time. Grower involvement in the project included use of the internet based scheduling service ‘WaterBalance’, hosting soil moisture monitoring sites, stalk growth measurements and seeking specific irrigation advice. One participating grower was a co-author of a paper reviewing the extension activities of the project (Webb, Inman-Bamber and Mock, 2006). Additionally, in 2006, 100% of growers claimed to have improved their irrigation knowledge through involvement with the project compared to 75% in 2004. The main
areas of increased knowledge nominated by growers were soil water holding capacity, daily crop water use, when to irrigate, how often to irrigate and cane growth monitoring.

The project was rated highly (second only to rain) by growers in influencing their irrigation management decisions. Advice on irrigation management from the agronomist was rated second only to the growers own experience. Almost 90% of growers have sought irrigation specific advice from the agronomist compared to 75% in 2004.

There were few marked differences in respect to irrigation number and amount between the responses in this survey and the last in 2004. For instance growers still largely do not routinely record the number and amounts of individual irrigations. Despite this, estimates by growers who answered these questions were very similar to those recorded in 2004. Most confirmed they use less water now than they did before the project commenced.

In 2004 growers had access to a model generated “in ute” guide to irrigation scheduling intervals. The 2004 survey indicated that some growers were using this guide. In 2006, 50% of growers indicated that they still referred to this guide occasionally.

A change in emphasis in the scientific framework from the APSIM growth model to the Penman-Monteith (PM) evaporation model was accepted by growers who have adopted “WaterBalance”, the new scheduling system based on real-time calculated daily crop water use. In 2004, growers were aware of the proposed new system and 92% indicated they would use real-time scheduling if they had access to the information. In 2006, 75% growers indicated that they actually were accessing and using the real-time scheduling information.

There was a marked change in the preferred method of delivery of scheduling related information, reflecting the growers increased use of internet based tools eg WaterBalance.

Relating to concern over the potential for furrow irrigation to impact on ground water levels, growers again demonstrated their awareness. Compared to the 2004 survey, an increased number of growers have taken action to minimise their potential impact on ground water. Some of the tactics nominated by growers included laser leveling; channel and drain maintenance; manipulating siphon size and number per shift; water only when required; managing tailwater time; minimise water sitting in channels:

Report on actual and potential impact of best practice irrigation on social, financial and environmental aspect of the Ord Irrigation Area.

In question 12 of the 2006 survey growers were asked the question: “If irrigation best practice was able to be fully implemented, what benefits do you envisage would be derived in terms of lifestyle, profitability and the environment?”

From their comments (Appendix 3) we can draw out the following benefits of applying best practice irrigation in the Ord.

Social aspects: Setting blocks up for best practice means matching slopes, supply head, siphon size and siphon number to fit in with normal hours of human activity. From interaction with growers it is clear that best practice irrigation includes considerations for family and social life for themselves and their employees. The improvement in lifestyle for both the grower and the employee has the potential to filter through into the broader community through time available to participate in community groups and activities. The survey data indicate that growers have reduced the amount of water used and it is likely that this has also made more time available for improving quality of lifestyle.

Financial: The documented reduction in water use has probably reduced labour requirement and therefore cost. Reduced cost from water savings is minimal in the ORIA at present due to the low cost of water. However there is potential for keeping irrigation costs to a minimum as the cost of water increases.
Survey CSR022 2003 2004 2006

Range/mean
ML per hectare 20-80/40 20-29 13-30/21 14-26/21
Number times 15-42/27 8-20 10-21/16 15-17/16

**Environmental:** Currently growers are acutely aware of the threat from downstream movement of fertilisers and pesticides in irrigation water. Current best practice (Compass workbook) is adhered to, and specially managed irrigations (i.e. no tailwater) could further improve performance.

A trial block of level furrow irrigation which has been established by one group will, if successful, lead to further increases in irrigation application efficiency and decreases in irrigation tailwater runoff. This novel technique allows water to flow on and off the paddock from same headland and could save considerable labour as well as improve irrigation efficiency.

Watertable presence is also managed by reduced total amount of irrigation water applied (see Mock statement in Appendix 3). With scheduling tools developed, sub-soil moisture (>80 cm) is not accessed by the crop and lack of soil cracking (the main route for water infiltration) will limit the amount of deep percolation from irrigation to that depth.

It is unlikely that total water use in the irrigation system will reduce as, although the system is extremely efficient from a cost to operate point of view, it was not designed as a water efficient system. It is a flow-through system – what is not applied to a paddock flows out the other end regardless. It is thought however that the environmental footprint has almost certainly reduced, as less water has flowed over paddocks in recent years thus reducing fertilizer and pesticide movement off the farm.

**Results of COMPASS questions in 2006 survey**

Growers scored highest in the area of soil health with an average of 1.38 out of a worst possible 4. This reflects local grower attitudes to the newly commenced SRDC Project WAA003, assessing new farming systems in the ORIA.

Attitudes to recycling tailwater rated 1.88 out of a worst possible 4. This reflects grower recognition of the potential environmentally damaging effects of excess tailwater removing chemicals, fertilisers, and soil off site. It is also a reflection of grower attitudes to minimising the total amount of irrigation water applied to their cane blocks, and the potential for deep drainage.

Growers also scored well with their attitudes towards scheduling irrigations. The worst result was in the area of farm planning. Only one grower, who has a land and water management plan, had anything other than a current mill map from which to plan their management decision making.

In terms of individual growers, four of the eight respondents averaged less than a score of 2 across all questions. No grower averaged higher than 2.5.

It will be interesting to compare these scores with those obtained from Eastern states growers, but indications are that ORIA growers already have a high degree of awareness of environmental management as it relates to their business.

**2. Guidelines (rules of thumb) for best-practice irrigation management developed, implemented and evaluated using an action research approach**

After presenting results of irrigation scheduling trials (CSR022) to growers at successive workshops (1999 to 2001) growers were asked how they would like scheduling advice to be formatted and communicated. One idea that was favoured by most growers was a simple table showing optimum intervals for irrigation for different parts of the growing season. In response to this, tables were developed from APSIM runs to include optimum intervals for different soils, different ratoon cycles, different rainfall categories, different refill and full points for each
calendar month. Growers found that this was too much information and so tables were simplified to include only the low rainfall category, average data for three soil types, three harvest dates and two refill deficits. The tables that were eventually circulated are shown below.
The ORIA irrigation scheduling guidelines used long-term climate data in conjunction with simulation modelling to develop best-bet irrigation intervals based on soil and irrigation characteristics. There were a number of limitations that needed to be understood before using these guidelines. Firstly, irrigators needed to assess how long to delay irrigation when rainfall was insufficient to fill the profile or to fully replace irrigation. A delay of one day per 10 mm rainfall was suggested. Secondly, if the crop experiences weather conditions significantly different to the long-term average, the guidelines will be less accurate.

After only one year of operation it was realised that this second limitation was quite severe. Radiation and temperature conditions seldom matched long term averages particularly for the stormy period leading up to the wet season. It was expected that averages would be appropriate for the dry season at least but experience soon showed that this was not the case.

3. Better definition of water requirements of sugarcane growing in the Ord as an input to water allocation policy (see also Appendix 4)

Introduction
A variety of approaches is available for estimating water use by crops. The most widely accepted practical method derives evapotranspiration ($ET_C$) for crops growing with adequate water, nutrition and free of pests and diseases, from a reference evapotranspiration ($ET_0$) using

$$ET_C = K_C . ET_0$$

where $K_C$ is an empirical crop coefficient, or 'crop factor'. $ET_0$ is calculated using a parameterisation of Penman-Monteith equation for a short-grassed surface written as (Smith et al., 1996):

$$ET_0 = \frac{0.408\Delta (R_n - G) + \gamma\frac{900}{T_2 + 273}uD}{\Delta + \gamma(1 + 0.34u)}$$

where $R_n$ is net radiation, $T$ is air temperature, $u$ is wind speed and $D$ is vapour pressure deficit, all at 2 m above the surface, $G$ is soil heat flux density, $\gamma$ is the psychrometric constant, and $\Delta$ is the slope of the saturation vapour pressure curve at temperature $T$.

Values of $K_C$ for sugarcane range from 0.4 to 1.25 for the initial (low canopy) and mid (full canopy) periods of crop development to 0.7 for the end (harvest) of development (Allen et al., 1998). The derivation of these data was not given by Allen et al. (1998). Inman-Bamber and McGlinchey (2003) determined $K_C$ for sugarcane using the Bowen ratio energy balance (BREB) method in Australia and Swaziland. They confirmed the validity of Allen’s $K_C$ values for the initial and mid periods of development but $K_C = 1.25$ was higher than Allen et al.’s during the final stages of crop development, provided water was not limiting. Doubt about transferring $K_C$ values obtained in the east to the Ord was fuelled by the changes in coefficients required to get APSIM to accurately simulate yield and water use in the Ord (see Background).

Research was undertaken to determine if crop coefficients developed for the Burdekin and Swaziland (Inman-Bamber and McGlinchey, 2003) could be applied to high temperature and radiation conditions of the ORIA and other similar climates in the world. The research was carried out under the close scrutiny of Ord sugarcane irrigators and the next section describes the participatory nature of this research leading to the development of a web-based scheduling service for these growers. The objective of the research reported here and more fully in Appendix 4 was to derive crop coefficients for the Ord and similar climates and to use these to determine annual irrigation requirements for sugarcane in the Ord.

**Materials and Methods**

All experiments were conducted on a Cununurra greyish cracking clay on the Northern Ivanhoe Plain (Plunkett and Muchow, 2003) of the Ord river irrigation area and all were furrow irrigated. One experiment was conducted on private land (Cummings Bros LTD) and two others at the Frank Wise Institute (FWI) of the Dept. Agriculture,
Western Australia (15.65ºS, 128.72ºE). Plant available water capacity for the Northern Ivanhoe soil was 129 and 190 mm to a depth of 1.0 and 1.9 m respectively (Plunkett and Muchow, 2003).

**Bowen ratio experiments**

A Bowen ratio energy balance (BREB) system similar to the one described by Inman-Bamber and McGlinchey (2003) was installed in a plant crop of sugarcane cv Q96 on a private farm in the Ord (Block 27). The field was 500 m by 600 m and the BREB was installed 20 m from the field boundary in the most common downwind position. This provided a fetch of more than 110 m in an arc of 200 degrees. The plant crop was planted late April and the BREB was operational by 6Sep02 when the crop was about 4.5 months old and had produced 25 cm of cane.

A second BREB experiment (BREB2) was initiated by installing the system in a third ratoon of Q99. The field was 400 by 580 m and the BREB was installed 25 m from the field boundary, again downwind of the most common wind direction. The fetch exceeded 140 m in an arc of 200 degrees. The field was ratooned after harvesting on 17Sep03 and the BREB system was operational by 10Oct03 when the crop was 3 weeks old.

Both experiments were irrigated and fertilized to provide unrestricted water and nutrients for cane growth. No particular irrigation schedule was followed in BREB experiment 1 (BREB1). Experiment 2 was scheduled using a system based on the APSIM sugarcane model calibrated for Ord conditions as described by Attard et al. (2003). The BREB system is described fully by Inman-Bamber and McGlinchey (2003).

**Reference evaporation**

An automatic weather station (AWS, Campbell Scientific) was installed in an open grassed area about 2 km from the BREB installations. AWS data were used to determine daily reference evapotranspiration (ET₀) from Allen et al. (1998, ‘FAO 56’).

**Soil water measurements**

In the BREB1 experiment, the only measure of soil water content was from two frequency domain reflectometers at an average depth of 40 mm required for determining soil heat capacity. In the BREB2 experiment, capacitance sensors were inserted to depths of 100, 200, 400, 600, 1000 mm at four locations within 50 m of the BREB installation.

**Results**

**Mid-growth \( K_c (K_{CMID}) \)**

Daily crop evapotranspiration (ETc) was determined only for days when more than 70% of the 20-min BREB data passed the acceptance criteria of Omura (1982) as described by Inman-Bamber and McGlinchey (2003). In addition, daily ETc was considered valid only when more than 70% of the 20-min readings were taken with wind in the right direction. In BREB1 only 26 valid daily ETc values were obtained under these strict acceptance criteria and most of these occurred after the canopy had developed sufficiently to intercept more than 80% of incident solar radiation. \( K_c \) exceeded 1.1 on only one of these days and 1.1<\( K_c \)≤1.0 on six days of valid readings.

BREB2 provided 113 valid \( K_c \) values when using the 70% acceptance criteria for instrument resolution and wind direction. Eight of these \( K_c \) values exceeded 1.0 but all were less than 1.2. The first set of 16 valid \( K_c \) values obtained after canopy interception reached 80% on 10 December 2003 (December and January) were generally greater than the second set (April and May) obtained after a long period of instrument failure (Figure 1). \( K_c \) was low in the second period on some days when the soil water sensors indicated that there was less than 375 mm of water in the top 1 m of soil. \( K_c \) was reduced when the soil was at the dry end of the range even though irrigation was meant to meet crop water requirement fully.
While mean $K_{C_{MID}}$ from BREB1 and BREB2 experiments was about 0.9 we chose to err slightly on the conservative side from a producer’s point of view, assigning the value of 1.00 to $K_{C_{MID}}$.

**$K_C$ for maturing cane**

In the second BREB experiment $K_C$ was distinctly lower in April and May when the crop was 7-8 months old compared to December and January. Ord crops are known for their poor growth after the wet season for unspecified reasons and the reduced $K_C$ may be a reflection of reduced biomass accumulation and water use at this stage. After discussion with Ord growers there was a preference to retain $K_C$ at 1.00 for maturing crops until more is known about when to reduce $K_C$.

**$K_C$ for a developing canopy**

The first valid $K_C$ recorded in BREB2 was 0.4 when about 10% incident solar radiation was intercepted by the canopy (Figure 1). FIR observed in BREB2 was simulated satisfactorily by APSIM-Sugarcane (Figure 1) which could then be used to estimate FIR for ratoons starting at any stage during the year. It is proposed that until more data is available, initial ($K_{C_{INIT}}$) should be 0.3 and $K_C$ should be directly related to FIR for 0.3<FIR<0.8. During rain or irrigation $K_C$ could be increased to 1.0 and then decreased by 0.2 for each day thereafter until $K_C$ = FIR. The decrease in $K_C$ after rain or irrigation was based on observations of soil surface drying in the field as well as suggestions for a dual crop coefficient approach by Allen et al. (1998). The canopy is effectively complete when $FIR=0.8$ (Inman-Bamber and McGlinchey, 2003) and then $K_{C_{MID}}$=1.0 can be used.

**Crop water requirement**

A simple water balance method based on $K_C$ for developing and complete canopy situations and an allowable deficit of 60 mm was run for the period 1970 to 2002 using manually captured climate data at the KRS weather station. Crops planted in April and harvested in September were simulated as well as four 12 month ratoon crops.
harvested throughout the milling season. Three initial and two final $K_C$ values were simulated to assess the importance of getting these values correct (Table 2).

Table 2. Minimum, maximum and median annual net irrigation requirement, $ET_C$ and effective rainfall for the Ord using some possible values for $K_{CINIT}$ and $K_{CEND}$ invoked 200 days after planting or ratooning. Mean annual rainfall at FWI=729 (mm)

<table>
<thead>
<tr>
<th>$K_C$ values</th>
<th>Net irrigation (mm)</th>
<th>$ET_C$ (mm)</th>
<th>Effective rain (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
<td>Med</td>
</tr>
<tr>
<td>0.2</td>
<td>671</td>
<td>1624</td>
<td>1247</td>
</tr>
<tr>
<td>0.2</td>
<td>579</td>
<td>1439</td>
<td>1112</td>
</tr>
<tr>
<td>0.3</td>
<td>670</td>
<td>1628</td>
<td>1256</td>
</tr>
<tr>
<td>0.3</td>
<td>578</td>
<td>1443</td>
<td>1118</td>
</tr>
<tr>
<td>0.4</td>
<td>730</td>
<td>1694</td>
<td>1297</td>
</tr>
<tr>
<td>0.4</td>
<td>600</td>
<td>1506</td>
<td>1142</td>
</tr>
</tbody>
</table>

Net annual irrigation requirement based on a conservative selection of $K_C$ values ($K_{CINIT} = 0.3; K_{CMD}=K_{CEND}=1.00$) was in the 670 to 1628 mm range. Effective rainfall may be less than was derived from the simple water balance particularly during high intensity storms which often occur in the Ord. Annualized $ET_C$ ranged from 1595 to 2160 mm (Table 2).

It is not easy to achieve high irrigation application efficiencies with the flow-through furrow irrigation system in the Ord. Muchow et al. (2001) obtained maximum yields with 2176 and 2957 mm annualized gross irrigation in 1999/2000. Mean annualized irrigation requirement for the experiment of Muchow et al. (2003) was 800 mm (rainfall = 1494 mm) based on our $K_C$ values. This indicates an application efficiency of about 40 % using the lower gross irrigation amount from Muchow et al. (2001). Gross annual irrigation requirements for the Ord based on this application efficiency would then range from 1675 to 4070 mm (median 3202 mm). It is likely that growers are more efficient (55 % by their own estimate) at applying irrigation than researchers; nevertheless application efficiency is an issue that may need more attention in the Ord.

Conclusions
The crop coefficient for well irrigated sugarcane with a fully developed canopy ($K_{CMD}$) is considerably lower in the Ord and similarly hot, dry and sunny environments, than it is in cooler and more humid climates. This arises because $ET_C$ from sugarcane does not exceed 8 mm d$^{-1}$ very often whereas $ET_0$ in these climates can reach 8 mm d$^{-1}$. 

This part of the report is based on a 2006 ASSCT paper entitled “Participatory irrigation research and scheduling in the Ord: Extension” by W.A. Webb, N.G. Inman-Bamber and P. Mock (Appendix 5).

The Ord sugar industry is relatively new with production starting only about 10 years ago. In that decade, numerous challenges have been successfully met by a small group of enthusiastic and competent growers. These challenges have had an impact on productivity, which has not yet achieved its potential. Not the least of the challenges faced by growers was optimising productivity in a very demanding climate. October to March maximum temperatures average 36.8°C, and often reach daily maximums in the low to mid 40°C's. These temperatures, combined with low day time relative humidity, severely distress plants introduced to this environment. Irrigation management under these conditions was outside the experience of Australian sugarcane researchers and growers.

The Ord irrigation scheme offered a chance to look at sugarcane crop water use from scratch and to apply new concepts for participatory action research (PAR). It was hoped that experience gained from research and extension of irrigation technology in the Ord could benefit older schemes such as the Burdekin. The PAR process involved two cycles of technology development and transfer. One involved the research team and the extension officer and the other the extension officer and the growers. This came about partly because of difficulties with regular interaction between growers and the research team based in Townsville.

Extension program 2003 to 2006

The APSIM-Sugarcane model (Keating et al., 1999) was the basic research tool introduced to Ord growers at the outset of the research work in the Ord. APSIM simulates a large number of biophysical processes in the soil and plant in order to provide industry with a range of guidelines including those relating to irrigation. In 2002/03, a scheduling system based on an APSIM-generated “in-ute” guide (see section 2), was being promoted to industry. At meetings growers expressed lack of confidence in this system because it did not take into account current seasonal conditions and it was based on some rather confusing (as perceived by growers) trial results. “My initial recollection of the project is that there seemed to be conflicting data which could not be explained, especially relating to a young crop and a lodged crop. The first year’s results seemed to indicate we were watering too often, so I reduced my irrigations in the following year. I remember that during October and November, many paddocks had cracks I could put my hand down because recommended irrigation times were extended. The second year’s results seemed to confirm that we had been underwatering at crucial times of the year. My confidence in the APSIM model on its own was pretty low. Regular workshops with the extension officer and researchers enabled these issues to be discussed, and I felt my contributions were listened to and responded to” - Mock.

There was probably some misunderstanding between researchers and growers as to exactly what growers wanted and what information package was a reasonable summary of research findings for use in irrigation management. In any case it was soon evident that averages do not apply, not even in the Ord with its apparently predictable weather.

On-farm scheduling and stalk growth monitoring sites

Extension activities were aimed at firstly assessing growers’ current practices, then offering advice on improved practices. This was done by establishing stalk elongation (growth) monitoring sites on each farm, recording irrigation frequency and monitoring soil water content with EnviroSCAN (ES) sensors in one case. Once current practice was established, growers were offered the collected information for consideration. Activities began during the 2002/03 crop with one grower, and continued with an increasing number of growers as the season progressed. The aim was to give growers (and the extension officer) confidence in irrigation scheduling techniques by showing them on-farm evidence of optimum irrigation management.

Advice was targeted at maximum productivity (i.e. optimum irrigation frequency for productivity). In this exercise, concern about the rising water table with increased irrigation frequency was largely ignored, as the issue could be addressed with other irrigation management practices such as modifying siphon sizes, row length and timely pulling of siphons. ES sensors at a depth of 1 m did not respond after irrigation indicating that irrigation water was not accessing the water table at the probe sites. Wet season rainfall did however reach the deep sensors but...
whether this deep drainage eventually accessed the water table was not measured, but is presumed. However, some sites may exist which allow access to the water table.

Growers were regularly updated on their crop’s progress with stalk elongation measurement and with two water balances, one based on a pan factor (PF) times daily Class A-pan evaporation (Holden, 1998), the other based on the Penman-Monteith (PM) equation for reference evaporation (ET₀) and a crop factor for sugarcane (K_C) as described in more detail by Inman-Bamber et al. (2006). With this information, growers were able to modify their schedules with confidence.

On one farm, Paul Mock’s, there was the opportunity to derive the water balances retrospectively and compare these with growth and ES measurements for a block that was scheduled differently in each of three years. The soil type in this block was a Northern Ivanhoe variation of a Cununurra clay (Plunkett and Muchow, 2003) with a total plant available water content (PAWC) of 200 mm, and readily available water (RAW) of 60 mm which was set as the irrigation refill point. The ES was not calibrated and readings were scaled to match the derived soil water deficits (SWD) by eye. ES readings were summed to a depth of 80 cm. “We started to make good progress when we measured stalk elongation and compared it with the SWD measured by ES. I also had the opportunity to use another measuring device which helped me to appreciate the complications in getting accurate data. These data helped us to better predict when irrigation was needed, and regular contact with the extension officer enabled me to reduce the number of times the 60 mm readily available water (RAW) target was exceeded. More frequent watering during October and November enabled a reduction in the watering schedule on most blocks either from 24 to 12 h shifts, or running an increased number of siphons per shift giving savings in irrigation of up to 40%” - Mock.

Three years of irrigation scheduling and stalk growth measurements on Paul Mock’s farm helped to provide a reality check and direction for the research program described by (Inman-Bamber et al., 2006).

**2002/03 “In-ute guide” scheduling**

This crop was scheduled with the “in-ute guide” and yielded 125 t ha⁻¹ after 13 irrigations in 384 days of growth (Table 3). Soil water deficits (SWD) derived from Class A pan and from ET₀ were very similar up to March 03 when a reduced K_C was being used. Measurements and calculations of the water balance all indicated that some large deficits developed while scheduling with the “in-ute guide” thus supporting the grower’s misgivings about this irrigation scheduling guide.

**2003/04 Class A pan scheduling**

This crop was scheduled with the “in-ute guide” initially and then with SWD derived from Class A-Pan readings. The crop yielded 131 t ha⁻¹ after 13 irrigations and 345 days of growth (Table 3). Growth measurements in this block indicated four distinct drying cycles corresponding to the large deficits derived from A-pan and ET₀ water balances. Daily stalk growth rate dropped by 50% when estimated SWD was about 60 mm during each of these drying cycles confirming that 60 mm was an appropriate estimate of RAW for this soil.

**2004/05 scheduling with the PM equation**

This crop was scheduled entirely with the ET₀ based water balance. The K_C regime was derived before the analysis of the Bowen ratio energy balance (BREB) results (the BREB system measures ET daily; see Inman-Bamber et al., 2006 for details) and the best guess regime at the time was K_CINIT=0.2, K_CMID=1.00 and K_CEND=0.75. The crop yielded 119 t ha⁻¹ after 18 irrigations and 392 days of growth (Table 3). The performance of the different scheduling regimes cannot be judged by the yield data for many reasons including a general decline in yield with later ratoons.
Comparisons and common features of the on-farm demonstrations

The target soil moisture deficit of 60 mm was generally exceeded using the APSIM schedule, but more regularly achieved using the A-pan and ET₀ systems. Productivity data indicate that exceeding this target deficit due to the practicalities of irrigating precisely “on time” was not unduly detrimental (Table 3).

Comparing yields between years is difficult because of differences in rainfall patterns, but Paul’s observations were that while A-Pan and ET₀ scheduling may require slightly more irrigations, they take less time, resulting in less overall water use through the Dethridge wheel, and less cost for water which has more than offset the cost of extra labour for the extra irrigations.

The period prior to canopy closure, an important period in crop establishment, should receive attention. There is some evidence (Allen et al., 1998) that a gradual increase of target deficit from 60% RAW to 100% RAW at canopy closure may be justified to allow for increasing root development. Conversely, the period is very short in terms of overall crop irrigation management, so minor modifications would have little effect on currently used irrigation schedules.

Table 3 – Productivity and irrigation summary using two methods for estimating crop water use (CWU) from Paul Mock’s block for crop years 2002/03, 2003/04 and 2004/05.

<table>
<thead>
<tr>
<th>Crop Detail</th>
<th>Cal. CWU mm</th>
<th>Productivity</th>
<th>Tonnes/ML</th>
<th>Mill Av TPH</th>
<th>Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harv Date</td>
<td>Age Days</td>
<td>Apan ETo</td>
<td>TCPH Pol%</td>
<td>Apan ETo</td>
<td>Actual</td>
</tr>
<tr>
<td>21/06/02</td>
<td>388 NA NA</td>
<td>156 13.0</td>
<td>6.2 7.5</td>
<td>131 119</td>
<td>APSIM 13</td>
</tr>
<tr>
<td>10/07/03</td>
<td>384 2029 1665 125 13.6</td>
<td>115 109</td>
<td>Aps/Apan 13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19/06/04</td>
<td>345 1727 1449 131 12.4</td>
<td>113 116</td>
<td>ETo 18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16/07/05</td>
<td>392 2004 1751 119 14.2</td>
<td>104 114</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: 2004/05 Wet season had lower than average and poorly distributed rainfall, thus requiring extra irrigations

The “WaterBalance’ Web program

While extension activity continues, research outcomes led to the development of WaterBalance, a computer program which growers have now readily adopted as a scheduling tool as a result of exposure to the methodology through extension. Growers had several suggestions which were incorporated into the web design. The logic used in the program was described by Inman-Bamber et al. (2006) and a test site has been made available at the following address for those interested in finding out how it works: http://www.cse.csiro.au/research/tropical/WaterBalance/WaterBalance_KUN_01/02/Main.aspx

The program requires the user to set up some simple details for each paddock including soil type, planting or ratooning dates and then to enter the date of irrigation and the amount if available. The system obtains hourly rainfall, radiation, temperature, humidity and wind speed from an automatic weather station in the Ord and calculates when the next irrigation should occur for each paddock (Figure 2).
“2005 involved the use of the website based scheduling. While it took me a while to have a look at it, once the extension officer showed me how to set it up, it was easy to see how it would be a great tool for scheduling and record keeping. Further modifications have made it easier to use and other recommended changes will happen soon. I now use the web based system for all my irrigation scheduling. We also modified the early crop RAW figures down to 40 mm manually, which should be incorporated soon. I look forward to comparing the web based deficit charts with the actual EnviroSCAN deficit charts, to see how accurate the whole system is” - Mock.

In January 2006, three Ord growers were actively using the prototype WaterBalance to schedule their irrigations. These growers have a total of 22 blocks on the system. A fourth grower obtains weekly updates on the current scheduling interval via fax or email. A fifth grower has entered data into the system, and commented on its usefulness. However he is not a regular internet user, so does not use the system for scheduling.

**Conclusions**
Irrigation scheduling has been adopted in the Ord where it might be expected to be of least value compared to high value crops in areas of water scarcity. The reasons for the success are considered to be:

1. Regular involvement of the Ord growers in the basic and applied research
2. Obtaining agreement from growers for future stages of research
3. Providing details of the research even if this seemed to be outside their immediate interest.
4. Honesty in presenting results even when these were conflicting at times.
5. Demonstration of scheduling options on-farm with key growers.
6. Working 1 to 1 with these growers.
7. An extension officer who was (and is) able to provide a reality check on the research results.
8. An extension officer committed to the interests of the growers.
9. Rapid response by the research team to needs of the extension officer and growers.
10. Development of a web system with a rapid response time, simple inputs and a simple presentation.

The data gathered during the on-farm demonstrations were important to facilitate independent verification of the research results in the eyes of the extension officer and the growers. The paper shows the importance of evidence based critique of new technology by possible end users.
5. Better understanding of the physiological basis of yield accumulation for different growth stages and soil types under Ord climatic conditions as input to model analysis and 6. Explanation of atmospheric drivers of crop evaporation using Bowen ratio, as input to model analysis

These two outputs are related to biophysics of the soil-plant-atmosphere continuum and will be discussed together based on two papers presented fully in Appendices 6 and 7.

Previous model analyses of the Ord sugarcane production system by Robertson et al (1997) and Keating and Muchow (1998) suffered from the assumption that physiological attributes determined for the east could be used in the Ord. The assumption was no doubt encouraged by the wide applicability of APSIM-Sugarcane to many sugarcane production systems worldwide (Keating et al., 1999). The APSIM-Sugarcane model (Keating et al., 1999) was introduced to Ord growers at the outset of the research work in the Ord since this was the theoretical framework used by the researchers who were conscious that generalisations from a few irrigation trials were possible only with such a framework. During the previous SRDC project (CSR022) certain adjustments were required for APSIM simulations under Ord conditions. Radiation use efficiency and hence crop water use had to be reduced after the crop had reached a certain biomass threshold (30 t ha⁻¹ or about 80 t ha⁻¹ of cane) in order to match simulated and measured crop water use and yield (Attard et al., 2003). Crop water use had to be reduced further by increasing transpiration use efficiency from 8.7 to 10.0 g kPa kg⁻¹.

Later on a framework based on reference evapotranspiration and crop factors was introduced to growers. This framework is concerned mainly with daily crop evapotranspiration (ETC) for which it is more suited than APSIM-Sugarcane but does not consider much detail on crop physiology or soil physics. It uses the Penman-Monteith (PM) equation (Allen et al., 1998) to derive reference evapotranspiration (ET₀). A crop factor (KC) is then used to obtain daily ETC (= KC x ET₀).

In this section we report a number experiments conducted to improve both the APSIM and PM frameworks for a better working knowledge of the soil-plant-atmosphere continuum in the Ord.

Methods

**APSIM scheduling trials**

Growers wanted to see how APSIM based scheduling compared with their own, so an experiment (#1) was designed to compare the two schedules on a 24 ha block at Frank Wise Institute (Block 9A). The ‘Grower’ treatment was scheduled by phoning a few key growers to find out when they were irrigating similar crops on similar soils. Two APSIM schedules were followed. One treatment (d50) was irrigated when the simulated soil water deficit (SWD) was 50% of PAWC and the other (s10), when simulated biomass accumulation was reduced 10% by delaying irrigation. Irrigation was assumed to refill 80% of PAWC. The treatments were applied randomly to four replicate blocks and plots were 12 rows wide (at 1.8 spacing) and about 500 m long.

The next APSIM scheduling experiment (#2) was superimposed on the second ratoon of Q99 in Block 9A after harvesting the first ratoon on 25 July 2002. The treatments of the previous experiment were repeated except that a 60% deficit (d60) was used instead of the d50 treatment. The extension officer at the time wanted to see if the crop could achieve maximum yields with even less water.

**New BREB experiments**

Two more BREB experiments followed those described in section 3. A third BREB experiment (BREB3) was conducted in field 9d on a first ratoon of Q95 harvested on 2 September 2004 and a forth experiment (BREB4) was conducted on a first ratoon of Q99 harvested on 5 May 2006 in field 11d at KRS.

Canopy development was measured in each BREB experiment except BREB1 by placing two 1 m long tube solarimeters end to end on the soil surface at an angle so as to span between two crop rows exactly.

A number of yield attributes including biomass yield were determined by hand sampling at various intervals in each BREB experiment except BREB1 using the procedure developed by Muchow et al. (1993).
Lodging algorithms were added to APSIM in 2004 (Inman-Bamber et al., 2004) and we thought that these may help explain the 'reduced growth' phenomenon in the Ord so the reduced growth threshold of 30 t ha\(^{-1}\) biomass was removed for the analyses of growth in the BREB experiments.

**PM scheduling experiment**

A first ratoon crop of Q96 in a 7 ha field (Field 7b) at FWI was subdivided into 12 plots, each 14 rows wide and 220 m long. Rows were 1.83 m apart. Four irrigation treatments were allocated randomly to four plots in each of the three replicate blocks. The treatments were designed to test a range of possible crop factors \(K_C\) for the Ord. All treatments were irrigated when the estimated soil water deficit was 60 mm. \(K_C\) was the same for all treatments until estimated fraction of intercepted radiation (FIR) reached 0.6. During this period \(K_C\) was assumed to be at least 0.2 and 25% greater than FIR in order to arrive at \(K_C = 1.0\) when \(FIR = 0.8\). This assumption was based on the observation that \(K_C\) reaches a maximum when \(FIR = 0.8\) in BREB experiments in Queensland (Inman-Bamber and McGlinchey, 2003).

FIR was calculated as \(FIR = a(1.0+\exp(b + cH))\) where \(H = S_0 + 0.3((T_{max}+T_{min})/2 -7.0)\), \(S_0\) = incident solar radiation, \(T_{max}\) and \(T_{min}\) are maximum and minimum daily temperature and \(a, b\) and \(c\) are non-linear regression coefficients (Inman-Bamber et al. 2006).

\(K_C\) was increased to 1.0 during rain or irrigation and was then reduced by 0.2 for each rainless day until \(K_C = FIR \times 1.25\). When \(FIR > 0.6\), a ‘Low’ irrigation treatment was irrigated using \(K_C = 0.75\). When \(FIR > 0.8\), a ‘Medium’ treatment was irrigated with \(K_C = 1.00\) and a ‘High’ treatment with \(K_C = 1.25\). A ‘Variable’ treatment was irrigated with \(K_C = 1.00\) until the crop was deemed to have produced 30 t ha\(^{-1}\) biomass at which point \(K_C\) was reduced to 0.75. APSIM-Sugarcane was used to determine when the critical biomass was achieved.

Yield was determined by mechanical harvesting as described by Muchow et al. (2001). There were three replications and area per plot was 0.78 ha.

**Results**

**APSIM scheduling trials**

For experiment 1 yields (hand sampled) were quite low for a first ratoon crop and there was little evidence of a yield difference between the grower and the d50 treatment. Yields of the s10 treatment were lowest for each sampling but no differences were statistically significant. The results of this trial were used to support the APSIM based schedule of the “in-ute” guide since the 19 irrigations of the grower treatment produced the same sucrose yield as the 13 irrigations of the d50 treatment (Table 4).

### Table 4. Cane and sucrose yields for replicated experiments 4 and 5 in the Ord comparing a grower and two APSIM schedules. Yields were determined by hand sampling (Muchow et al., 1993). Statistical significance: *\(P = 0.05\), **\(P = 0.01\).

<table>
<thead>
<tr>
<th>APSIM scheduling experiment</th>
<th>Age (d)</th>
<th>Treatment</th>
<th>No. irrigations</th>
<th>Treat 1</th>
<th>Treat 2</th>
<th>Treat 3</th>
<th>P</th>
<th>Treat 1</th>
<th>Treat 2</th>
<th>Treat 3</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block 9a</td>
<td></td>
<td></td>
<td></td>
<td>Grower</td>
<td>d50</td>
<td>s10</td>
<td></td>
<td>Grower</td>
<td>d50</td>
<td>S10</td>
<td></td>
</tr>
<tr>
<td>Q99 1R Ratooned</td>
<td>100</td>
<td>3/12/01</td>
<td>150</td>
<td>73</td>
<td>80</td>
<td>68</td>
<td></td>
<td>-</td>
<td></td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>6/7/01</td>
<td>200</td>
<td>9/4/02</td>
<td>277</td>
<td>103</td>
<td>114</td>
<td>100</td>
<td>12.6</td>
<td>13.4</td>
<td>10.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>26/6/02</td>
<td>355</td>
<td>110</td>
<td>114</td>
<td>109</td>
<td>16.1</td>
<td>16.1</td>
<td>14.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Block 9a</td>
<td></td>
<td></td>
<td></td>
<td>Grower</td>
<td>d60</td>
<td>s10</td>
<td></td>
<td>Grower</td>
<td>d60</td>
<td>s10</td>
<td></td>
</tr>
<tr>
<td>Q99 2R Ratooned</td>
<td>100</td>
<td>13/11/02</td>
<td>111</td>
<td>30</td>
<td>20</td>
<td>22</td>
<td></td>
<td>-</td>
<td></td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>6/7/02</td>
<td>200</td>
<td>1/4/03</td>
<td>250</td>
<td>100</td>
<td>90</td>
<td>76</td>
<td>*</td>
<td>12.1</td>
<td>10.6</td>
<td>8.0</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>9/9/03</td>
<td>411</td>
<td>90</td>
<td>78</td>
<td>75</td>
<td></td>
<td>13.9</td>
<td>12.2</td>
<td>11.2</td>
<td></td>
</tr>
</tbody>
</table>
For experiment 2 cane and sucrose yields were lower in the d60 treatment than the grower treatment for each sampling. Treatment effects were significant only for the second sampling (Table 5). We concluded that a 60% deficit was too large and that a 50% deficit represented the lower limit of readily available water (RAW). Assuming (from CSR022) that furrow irrigation in the Ord only fills the soil profile to 80% PAWC it was possible to derive RAW for the major soil types in the Ord as in Table 3.

Table 5. Readily available water (RAW) and plant available water capacity (PAWC) for Ord soils (Plunkett and Muchow, 2003).

<table>
<thead>
<tr>
<th>Soil type</th>
<th>RAW (mm)</th>
<th>PAWC (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern Ivanhoe</td>
<td>60</td>
<td>200</td>
</tr>
<tr>
<td>Central Ivanhoe</td>
<td>68</td>
<td>226</td>
</tr>
<tr>
<td>Southern Ivanhoe</td>
<td>50</td>
<td>167</td>
</tr>
<tr>
<td>Aquitaine</td>
<td>56</td>
<td>187</td>
</tr>
</tbody>
</table>

**BREB experiments**

*Leaf cover*: APSIM simulated FIR was lower than measured interception during the first 2 months of development in each of the experimental crops (Figure 3). After 2 months simulated interception was lower than measured interception for BREB2, was similar to measured interception for BREB3, and it was slightly greater than measured interception in the BREB4 crop. Simulated and measured interception were similar in all crops after the latter reached about 80% which is when $K_C$ is expected to reach a maximum (Inman-Bamber and McGlinchey, 2003).

![Figure 3](image-url)

**Biomass and cane yield**: Before February biomass accumulation in the BREB2 crop was slow relative to simulated biomass and then caught up with the simulation in March and then slowed considerably after about 35 t ha$^{-1}$ biomass had been produced. Measured biomass accumulation in the BREB3 crop was as rapid as could be expected from the APSIM-Sugarcane simulations until February and then growth rate slowed down when about 40 t ha$^{-1}$ biomass had accumulated. Biomass measured in the BREB4 crop was similar to simulated biomass for 8 of the 11 samplings and lower in the remaining 3 samplings (Figure 4). Measured growth of this crop slowed down when it had produced about 50 t ha$^{-1}$ biomass and this corresponded with a reduction in simulated growth due to simulated lodging. Although lodging was not measured it was noted that extensive lodging occurred after heavy rains in April 2006. The cane yield for this crop was well above the industry average (112 t ha$^{-1}$) for 2004 and 2005 (Webb, 2006) but yields for the other crops were less than the industry average (Table 6). The sucrose content for BREB2 was high and compensated to some extent for the low cane yield.
Figure 4. Above ground biomass measured (symbols) and simulated (lines) for BREB2 (△—△), BREB3 (□---□) and BREB4 (○★★) experiments.

Table 6. Yield and sucrose content of experimental crops measured at the final sampling of each crop.

<table>
<thead>
<tr>
<th>Date</th>
<th>Experiment</th>
<th>Biomass (t ha⁻¹)</th>
<th>Cane yield (t ha⁻¹)</th>
<th>Sucr. Cont. (%)</th>
<th>Sucr. yield (t ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25/07/2006</td>
<td>BREB4</td>
<td>64.5 ±2.3</td>
<td>158±4.7</td>
<td>14.5±0.5</td>
<td>22.9±1.3</td>
</tr>
<tr>
<td>28/06/2004</td>
<td>BREB2</td>
<td>38.6±2.8</td>
<td>85±7.0</td>
<td>18.1±0.1</td>
<td>15.4±1.3</td>
</tr>
<tr>
<td>5/04/2005</td>
<td>BREB3</td>
<td>44.4±2.3</td>
<td>105±4.8</td>
<td>16.2±0.2</td>
<td>17.1±0.9</td>
</tr>
</tbody>
</table>

*Kₚ prior to canopy closure*: BREB4 had sufficient valid data for an analysis of *Kₚ* from the early stages of canopy development to 80% canopy closure. *Kₚ* was about 0.25 shortly after the BREB system was installed and canopy cover was about 10% (Figure 5). *Kₚ* rose to 1.4 after the next irrigation and to similarly high values after the next three irrigations. *Kₚ* decreased as the soil surface dried and it increased gradually as the canopy continued to develop. An equation  

$$Kₚ = 1.08 - exp(-3212I) + 0.653\Phi^3$$  

(3) including terms for relative soil water content (Φ) near the surface and fractional light interception (I) was fitted to *Kₚ* data in Figure 5 and accounted for 74% of the variation in measured *Kₚ*. Thus the equation incorporates vegetation and soil components of the ‘dual *Kₚ* approach’ of Allen et al (1998). *Kₚ* increased with canopy development at a diminishing rate and it increased with soil water content near the surface at an increasing rate. The very high *Kₚ* values after irrigation were likely to result from the presence of flowing or ponded water in the irrigation furrows for periods of up to 24 hours.
**Figure 5.** $K_C$ measured (symbols) and estimated from eqn 3 (---), and measured radiation interception (----) and relative soil water content at a depth of 60 mm (---) for the BREB4 experiment. Vertical dotted lines show dates of irrigation.

$K_C$ 5-day means after canopy closure: $K_C$ was influenced significantly by relative soil water content after canopy closure (>80% radiation interception) in all experiments ($p=0.005$, 0.013 and 0.047 for experiments BREB2, BREB3 and BREB4). Relative soil water contents between 0.5 and 1.0 had no significant effect on $K_C$ in any experiment ($p=0.419$, 0.769 and 0.614 for experiments BREB2, BREB3 and BREB4) and BREB data for only the wetter range of soil conditions were included for the following analysis of climate and crop effects on $K_C$.

Valid 5-day $K_C$ means were obtained throughout the calendar year only for the BREB2 crop (Figure 6). Only 5 valid means were obtained for the BREB3 crop and these were in the wet season (Dec to March) whereas valid $K_C$ values for the BREB4 crop were in the dry periods September to November and April to June (Figure 6). $K_C$ was mostly less than 1.0 for the BREB2 and BREB3 crops. After the wet season $K_C$ was 0.4 to 1.1 for the BREB3 crop and was mostly greater than 1.0 for the BREB4 crop. Prior to the wet season $K_C$ was between 0.6 and 1.3 for the BREB3 and BREB4 crops. The high $K_C$ values in September for BREB4 occurred when $ET_0$ was also at peak values for the season and mean 5-day $ET_0$ was about 8 mm d$^{-1}$. The difference in $K_C$ after the wet season between BREB2 (low) and BREB4 (high) is interesting because neither crop was growing much at the time but BREB4 had reached nearly twice the biomass of BREB2. The regression of $K_C$ means on total biomass was significant ($p=0.05$, $Y=0.81+0.0043X$ (X in t ha$^{-1}$)) when data from all experiments was pooled but not for individual experiments. The regression on biomass gain between samplings was not significant. There appears to be no reason other than the size of the crop to explain the large difference in $K_C$ between BREB2 and BREB4 after the wet season. High $K_C$ values for BREB4 in September may be due to the influence of soil evaporation in a canopy that was not quite complete (Figure 5).
Figure 6. $K_c$ measured in three experiments during 2003/04 (BREB2 △), 2004/05 (BREB3 □) and 2005/06 (BREB4 ○) and mean monthly reference evapotranspiration ($E_T$) for BREB2 (——), BREB3 (---) and BREB4 (•••).

**PM Scheduling experiment**

The four treatments were irrigated three times simultaneously during canopy development and 11, 13, 14 and 17 times thereafter for the Low, Medium, Variable and High treatments respectively (Figure 7). Irrigation amount was not known and it was clear from the soil moisture measurements that the profile was not always refilled completely after each irrigation (Figure 7).
The mean sucrose % cane for all samples was 13.5 % and mean sucrose yield was 17 t ha⁻¹ which is a high yield for Ord ratoons. Cane yield was reduced significantly when less than 17 total irrigations were applied in the Variable and Low treatments, both using a mid-season \( K_C = 0.75 \) at some stage (Table 7). The yield difference between the Medium and Variable treatment was 5 t ha⁻¹, with only one less irrigation. In March and April, water deficits in the Variable treatment were large compared to the Medium and High treatments (Figure 7) and these large deficits probably resulted in the yield loss. The three additional irrigations required by increasing \( K_C \) from 1.0 to 1.25 did not increase yield significantly (Table 7).
Table 7. Mean cane yield for four irrigation treatments of the scheduling experiment.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Total Irrigations</th>
<th>KC</th>
<th>Cane Yield (t ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>14</td>
<td>0.75</td>
<td>121</td>
</tr>
<tr>
<td>Variable</td>
<td>16</td>
<td>1.00/0.75</td>
<td>126</td>
</tr>
<tr>
<td>Medium</td>
<td>17</td>
<td>1.00</td>
<td>131</td>
</tr>
<tr>
<td>High</td>
<td>20</td>
<td>1.25</td>
<td>133</td>
</tr>
<tr>
<td>LSD (p=0.05)</td>
<td></td>
<td></td>
<td>4.3</td>
</tr>
</tbody>
</table>

**Discussion**

The three BREB ratoon crops discussed here produced markedly different biomass yields depending on the ratoon date and ratoon age. Because the crops were grown in different years they needed to be compared through the APSIM-Sugarcane benchmark. The model integrated temperature, rainfall, irrigation and radiation inputs as best as currently possible to show that all crops accumulated biomass nearly as well as could be expected at least up to a point. Biomass accumulation in the BREB2 crop practically stopped when it had produced about 30 t ha⁻¹ biomass even though it was still erect and should have kept growing according to the APSIM simulation. This was the type of data that encouraged the 30 t ha⁻¹ trigger for reduced biomass accumulation in APSIM (Inman-Bamber et al., 2006). The BREB3 crop grew slightly less than expected from the APSIM simulation after 40 t ha⁻¹ biomass had accumulated. The lodging threshold was reached in APSIM at about this time and subsequent growth simulation would have been reduced had the experiment continued. The BREB4 crop slowed down when about 55 t ha⁻¹ biomass was reached and this was explained by the lodging rules in APSIM when a large storm in March exacerbated lodging (simulated and observed). KC for the August and September ratoons seldom exceeded 1.0 whereas KC for the BREB4 crop often exceeded 1.0 with a overall mean value of 1.09 compared to 0.89 for BREB2 and 0.92 for BREB3. Thus KC increased with crop yield which is to be expected since biomass accumulation and transpiration are normally highly correlated. KC prior to canopy closure depended on canopy cover and soil water content near the surface as may be expected. Both the measurements and modeled KC in Figure 5 resembled the stylized dual crop coefficient curve in Smith (2000) where the contribution from soil evaporation (KE) causes KC to reach 1.4 after rain or irrigation and then KC declines to a base level (KC₈) determined by the level of crop cover.

The PM scheduling experiment indicated that using KC = 1.0 was appropriate for achieving near maximum yields and avoiding water wastage. Yield was not improved by increasing KC to 1.25 even though this was a high yielding crop (about 130 t ha⁻¹) compared to the average yield in the Ord for 2005 (111 and 144 tons ha⁻¹ in 2002 and 2003, Mock (2004)).

**Conclusions**

The lodging rules in APSIM developed for conditions in the east were able to explain the slow down phenomenon in an early ratoon crop in which the accumulation of biomass was rapid until 55 t ha⁻¹ biomass had accumulated. Thus the fixed 30 t ha⁻¹ threshold assumed during the CSR022 project and for most of CSE007 can be replaced by these rules which are based on antecedent soil water content, biomass and storm rainfall amount. The CSE007 data and reviewed data presented here supported an upper limit for ETₐ in sugarcane of 8 mm per day world wide. An equation based on canopy cover and soil water content near the soil surface explained more than 70% of the variation in KC prior to canopy development. This will be useful in simulations of the water balance based on the PM equation. RAW for all major soil types in the Ord could be derived from the various scheduling trials.
7. WaterSense

*WaterSense* is a web-based process level model for scheduling irrigation in sugarcane, developed for users of unlimited irrigation water (like Ord growers) from CSE007 funds and for users of limited water in the Bundaberg/Isis region from CSE009 funds. *WaterSense* combines two earlier web-based irrigation DSSs, one for growers with limited water in the Bundaberg/Isis region of Queensland (Inman-Bamber et al., 2005) and the other for growers in the Ord irrigation scheme with abundant water (Webb et al., 2006). The development of *WaterSense* which is a combination of two earlier web tools is fully described in Appendix 8.

**Methods**

An optimisation procedure (‘Caneoptimiser’) based on the APSIM-Sugarcane model (Keating et al., 1999) was developed for applying irrigation when most needed to limit yield loss due to water stress. Growers proposed a competition between their way of using limited water and the solution offered by *Caneoptimiser*. After three years of replicated comparative field experiments on two private farms, it was clear that *Caneoptimiser* and experienced growers scheduled irrigation in a similar manner (Inman-Bamber et al., 2002). Growers requested access to *Caneoptimiser* and this was provided over the Internet (Inman-Bamber et al., 2005).

The research and grower interaction underpinning the development of *WaterBalance* for Ord growers was described in section 3 and in Appendices 5 and 6. *WaterBalance*, which schedules irrigation based on simple inputs of planting or ratooning date and target soil water deficit, appealed to Bundaberg growers and they asked for a service that offered the optimisation facility of *Caneoptimiser* at the speed and format of *WaterBalance*. *WaterBalance* and *Caneoptimiser* were essentially combined to form a new service called ‘*WaterSense*’. *Caneoptimiser* (APSIM) contributed the algorithms for canopy development and soil water hydrology while *WaterBalance* contributed algorithms for ET₀ and crop factors. *WaterSense* now simulates canopy development and soil water processes programmed in APSIM-Sugarcane without requiring direct access to the APSIM model.

**Results**

A simulation of a crop ratooned with a trash blanket on 15 June 2005 on a Red Dermosol in Bundaberg illustrates how *WaterSense* will be used for those with limited and unlimited water (Figure 8). A grower with unlimited water will select a soil water deficit (SWD) that should not be exceeded. This SWD threshold will usually be the amount of water considered to be readily available to the plant. Irrigation is scheduled whenever this deficit is exceeded, subject to the minimum irrigation cycle of the infrastructure. The model calculates and displays a selection of parameters such as canopy ground cover, SWD at a selection of soil depths and a water stress factor (Figure 8a). Simulation continues into the future using average temperature and radiation regimes to predict the next irrigation date, assuming that no rain occurs before this date. Users are encouraged to update the schedule often to take current rainfall and other climate variables into account.
A grower with limited water cannot achieve potential yield. A target stress level needs to be selected in relation to the amount of water available, the soil type and the climate. This can be done by Caneoptimiser or by the grower. The model will schedule an irrigation event when water stress is about to reduce yield accumulation more than the specified target value (Figure 8b). The example in Figure 8b shows a situation where the growth threshold is 80% of potential. A relative growth indicator, which is reset after 20 mm rain plus irrigation, is displayed and irrigation is scheduled whenever this indicator crosses the selected threshold. The optimum relative growth threshold changes only gradually during the season and can be obtained from Caneoptimiser when the user is offline. SWD over the full rooting depth will be greater in the limited than the unlimited scenario (Figures 8a and 8b).

The service offers the opportunity for those with unlimited water to irrigate only when necessary. This can be done by setting the relative growth threshold to 100% (Figure 8c). The model will schedule irrigations as soon as a drop in relative growth rate is imminent. Yields for a schedule based on SWD and one based on growth rate will be similar,
but the amount of irrigation could be substantially reduced for the latter scenario depending on rainfall (450 mm vs 700 mm in the example).

**Discussion**

*WaterSense* has been endorsed by the BSES Limited, the Sugar Research and Development Corporation and the Cooperative Research Centre for Irrigation Futures. These organizations will continue to be involved in the further development of *WaterSense* and its adoption in the sugar and possibly other cropping industries. Adoption by those growers familiar with the background research has been immediate. Indications are that the combined use of the Internet, PAR and concurrent research and demonstration will open the way for the adoption of research findings in the management of irrigation and possibly other aspects of sugarcane farming. However, widespread adoption of DSSs cannot depend on participation of the intensity required for their development. The intensive involvement of growers in both the definition of the problem that *WaterSense* addresses and the specific design of the software interface will have “embedded” much of the expert knowledge of the growers and scientists into the tool. *WaterSense* may therefore become a product like a new variety or soil moisture gauge with embedded technology, making it more amenable to promotion by traditional extension techniques (Jakku and Thorburn, 2007).

**OUTPUTS**

The outputs were reported in detail above.

**INTELLECTUAL PROPERTY**

*WaterSense* was developed partly on funds from CSE007. SRDC and CSIRO have contributed substantially to the development of *WaterSense* which is now quite distinct from APSIM. APSIM is owned by APSRU. We have talked to APSRU about *WaterSense* and this agency could be asked to manage the IP arrangements. The CRC IF have also contributed a small amount to its development and are interested in claiming some ownership. Ongoing support for *WaterSense* will have to be negotiated with all these agencies and with the users.

**ENVIRONMENTAL AND SOCIAL IMPACTS**

From section 1

**Environmental**

Currently Ord growers are acutely aware of the threat from downstream movement of fertilisers and pesticides in irrigation water. The results of the final evaluation survey could be compared directly with a mid-term survey conducted in 2004 and indirectly with a benchmarking survey for this project conducted in 2003 and with the benchmarking survey for a previous project (CSR022) conducted in 1996. The most remarkable difference between the original survey in 1996 and the 2006 survey is a reduction of average water used per annum per hectare of sugarcane from about 33 ML ha⁻¹ yr⁻¹ to about 21 ML ha⁻¹ yr⁻¹. The average water actually used in 1996 was 40 ML ha⁻¹ because the industry was based largely on plant crops older than 12 months.

A trial block of level furrow irrigation which has been established by one group will, if successful, lead to further increases in irrigation application efficiency and decreases in irrigation tailwater runoff. Watertable presence is also managed by reduced total amount of irrigation water applied (see mock statement in Appendix 3). With scheduling tools developed, sub-soil moisture (>80 cm) is not accessed by the crop and lack of soil cracking (the main route for water infiltration) will limit the amount of deep percolation from irrigation to that depth.

**Social aspects**

Setting blocks up for best practice means matching slopes, supply head, siphon size and siphon number to fit in with normal hours of human activity. From interaction with growers it is clear that best practice irrigation includes considerations for family and social life for themselves and their employees. Irrigation is highly labour intensive and as the number of irrigations has declined so more time has been freed up for Ord growers. The improvement in lifestyle for both the grower and the employee has the potential to filter through into the broader community through time available to participate in community groups and activities.
EXPECTED OUTCOMES

The most remarkable outcome for the Ord has been the reduction of average water used per annum per hectare of sugarcane from about 33 ML ha⁻¹ yr⁻¹ to about 21 ML ha⁻¹ yr⁻¹. Grower surveys indicated that all respondents claimed to have improved their irrigation knowledge through involvement with the project. The main areas of increased knowledge nominated by growers were soil water holding capacity, daily crop water use, when to irrigate, how often to irrigate and cane growth monitoring. The project was rated highly (second only to rain) by growers in influencing their irrigation management decisions. It is therefore reasonable to assume that the project has had some influence in reduced water use in the Ord.

CSE007 has contributed substantially to the development of WaterSense which is now being used and promoted in several cane production regions of Queensland. It is reasonable to expect that the benefits from CSE007 will be transferred to these regions through the use of WaterSense if adoption is successful.

FUTURE RESEARCH NEEDS

We still don’t know exactly why biomass accumulation slows down in the Ord particularly in erect crops. This slow-down has also been documented in the east and is not always associated with lodging (Park et al., 2005). Reduced growth rates in maturing crops may be unavoidable but until we know what causes this phenomenon we will not know if there are any possible solutions. If we knew exactly what caused biomass (and sucrose) accumulation to slow down we could model these processes and then suggest a harvesting schedule to avoid the causal conditions (including crop age) as best as possible. This may lead to harvesting crops at an earlier age which may not only increase yield accumulation rate (sucrose per month) but make it easier for growers to included break crops in rotation with cane. This practice has shown to be highly beneficial to soil health and crop yields.

Dr Frank Dunin, the science expert on the mid-term review panel, highlighted possible factors to be analysed in relation to ‘growth slow-down’ including low temperature, soil water distribution with depth, low N and K, respiration and water logging. He also proposed a trickle irrigation treatment to assess the possible role of water stress between irrigations associated with a correlation between Kc and soil water content after canopy closure. Future work with the BREB should include a high resolution infra-red gas analyser to measure CO₂ flux. This will help identify the role of respiration in growth slow-down (or lodging) for the Ord and for crops in the east.

RECOMMENDATIONS

CSE007 presented an opportunity to identify technical and social processes required for the development and adoption of complex decision support tools along with a dedicated project with these aims, CSE009 (Beyond case studies). While adoption of WaterSense is only starting in the east, it seems that both projects have been successful in highlighting what is required for scientists, extension staff and their growers to understand how grower issues can be addressed by science. SRDC has recognised that WaterSense has a chance of making an impact on water use (and related environmental consequences) by being adopted more widely in the east and has funded a project (BSS297) to assist this adoption. However an essential component of the adoption process identified in CSE007 and CSE009 is missing in the new project. Growers and EO’s require current and local proof that the new technology works as was shown in CSE007. It would not be necessary to repeat the elaborate replicated trial program of CSR022 and CSE007 to support the adoption of WaterSense but sceptical EO’s and growers will need to see how WaterSense matches their expectations at least in terms of crop canopy development, stalk elongation and soil water deficit. Strip trials like the PM scheduling trial were convincing for Ord growers and would greatly support the adoption of WaterSense in the east.

We recommend that SRDC support the further development and adoption of WaterSense in the east not only for use by growers but also by water providers and regulators. WaterSense could become the standard for assessing best management practice for irrigation as well as a database on regional water use and estimates of runoff and drainage. Once a standard method of managing and recording water use is established it is not difficult to visualise a regional balance sheet for compounds that move with water such as N compounds.
REFERENCES


PUBLICATIONS

Refereed conference papers


Conference abstract

Popular articles


Landline interview
## LIST OF APPENDICES

| Appendix 2. | Survey of irrigation practice and attitudes in the ORIA sugar industry - 2004 |
| Appendix 3. | Survey of irrigation practice and attitudes in the ORIA sugar industry - 2006 |
| Appendix 4. | Crop coefficients and irrigation requirement for sugarcane in high temperature conditions |
| Appendix 5. | Participatory irrigation research and scheduling in the Ord: Extension |
| Appendix 6. | Participatory irrigation research and scheduling in the Ord: R&D |
| Appendix 7. | Daily water requirements for sugarcane in the Ord River irrigation area. |
| Appendix 8. | A web-based system for scheduling irrigation in sugarcane |
| Appendix 9. | Why knowing ET is central to crop water needs. Australian Canegrower, 10 April, 2006 |
| Appendix 10 | Sugar report. Kimberly Echo. 1 December, 2005 |
| Appendix 11 | Ord growers building irrigation capacity. Australian Canegrower, 12 December, 2005 |
APPENDIX 1

CANE GROWER SURVEY: WATER MANAGEMENT ISSUES OF THE ORD RIVER IRRIGATION AREA

Department of Agriculture, Western Australia

AUGUST 2003
EXECUTIVE SUMMARY
The Ord Irrigation Cooperative (OIC) and the Department of Agriculture Western Australia (DAWA) have worked in partnership to survey 19 of OIC's customers to explore local growers’ knowledge, perceptions, and irrigation practices in relation to water management issues of the Ord River Irrigation Area (ORIA).

The purpose of the survey was to provide data contributing to the OIC's Water Use Improvement Program, DAWA's involvement with a Sugar Research and Development Corporation (SRDC) Irrigation Project and DAWA’s annual Farm Business Review.

The survey of 19 OIC customers included a sub group of 8 cane growers. The following are the key results obtained from survey of this sub group.

- 100% of survey participants stated that they thought it was important that environmental impacts caused by irrigation should be managed, and 100% stated that they were interested in changing their farm practices to help contribute to addressing these issues.

- Survey participants' perceptions on crop water requirements, number of irrigations per season, and irrigation intervals were variable. The average of survey participants' perceptions of current on-farm water use efficiency was 55%.

- All survey participants rated their knowledge of environmental issues and solutions as average or high, and the majority of survey participants rated their knowledge of locally relevant water management programs as average or low.

- The large majority of survey participants have taken part in a range of improved water management practices on their properties. The greatest limiting factor in preventing enhanced participation in these practices includes a lack of time and business inability to pay for changes on-farm.

- Field trips and targeted group training sessions were the greatest supported types of communication mediums by survey participants. Survey participants stated they would more likely respond to communication mediums if they are brief, relevant and if they suit their work schedules.

- Key issues identified by participants as affecting the long term profitability of farm businesses in the ORIA were resources/environment, DAWA support, business operational issues and land availability. DAWA's role in addressing these issues was identified as communication with farmers, approach to research, increased knowledge and business/regional support.

It is important to note that no interpretation of the results or recommendations have been made within the Report as there may be a number of sources accessing and utilising the results.

1. BACKGROUND
In May 2003, staff from the Ord Irrigation Cooperative (OIC) and the Department of Agriculture Western Australia (DAWA) recognised that their respective organisations were planning to survey the same target audience, that being the Ord River Irrigation Area (ORIA) growers.
In an attempt to minimise time input from growers, and to work towards achieving efficiency gains through collaboration of industry and agency, it was agreed that both organisations would work in partnership to implement one survey.

2. PURPOSE
The purpose of the survey is as follows:

- Collection of baseline data of ORIA grower's perceptions, knowledge and practice in relation to water management issues, to form the basis of comparison of future activities by the OIC.

- Collection of data to be used in the preparation of the OIC's Water Use Improvement Program, which will guide the OIC in achieving its' surface water licence responsibilities.

- Collection of data from a subset of sugar growers for a DAWA Sugar Research and Development Corporation Project on irrigation management for the Ord River Irrigation Area (ORIA) sugar industry.

- Collection of data to be used in the preparation of DAWA Regional Farm Business Review that assists the Agency to focus on medium to longer term planning.

3. PROCESS
The process of implementing the survey, and developing the Report was as follows:

- A draft survey was designed by the OIC and DAWA. Confidentiality arrangements were established, the basis of which was that three agency staff, Meroe Bok, Francis Bright and Joe Sherrard would be the only individuals with access to individual growers survey responses.

- Ord Land and Water (OLW), Water and Rivers Commission (WRC), and Ord-Bonaparte Program (OBP) representatives were provided an opportunity to provide comment on the survey design.

- 19 Growers were randomly selected using a random number generator within the Microsoft Excel Program from the OIC customer database of 72 growers, of which 8 were targeted from a DAWA cane grower database.

- Growers were contacted for an on-site interview. At this time growers were provided background information on the survey, and notified of the confidentiality protocols.

- Interviews were conducted within a timeframe range between 30 to 70 minutes.

- Electronic copies of each interview were recorded.

- Collated results were recorded into a Microsoft Excel spreadsheet. A coding system was utilised to adhere to confidentiality protocols for both the whole sample and the sugar grower sub-sample.

- Analysis of collated results was completed using Microsoft Excel functions for both the whole sample and the sugar grower sub-sample.

OIC DAWA Survey

- A draft report on the full data set was prepared, for which OLW, WRC and OBP were provided opportunity to provide comment. In addition, three survey participants were asked to provide comment on the Final Draft Report.
A final report was released as a public document. All survey participants were provided a copy.

**DAWA/SRDC Survey of sugar growers**

- A draft report on the full data set was prepared and general comments obtained from OLW, WRC and OBP for the DAWA/OIC report were applied to the DAWA/SRDC report.

- A final DAWA SRDC report was released as a public document. All cane growers who participated in the survey were provided a copy as well as SRDC and a copy placed in the DAWA Library at Frank Wise Institute, Kununurra.

- Note: The DAWA/SRDC Survey report has been developed using the same structure and majority of the text that is contained in the OIC’s Grower Survey: Water Management Issues of the Ord River Irrigation Area, prepared by Meroe Bok of OIC and Francis Bright, Department of Agriculture WA. Where it differs from the original report, is that the data set, data analysis, summary tables and graphs relate only to the practices, perceptions and knowledge of the sugar growers surveyed.

- Permission was granted by the primary author, Meroe Darke, of OIC, for the text and format to be copied into the DAWA/SRDC report. An advantage of having the two reports of a similar structure is that some organisations may wish to compare differences between the results of the sample’s survey and the results the sugar sub sample survey.

4. **ROLES AND RESPONSIBILITIES**

The project team was as follows:

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joe Sherrard</td>
<td>DAWA</td>
</tr>
<tr>
<td>Andrew Kelly</td>
<td>OIC</td>
</tr>
<tr>
<td>Robert Donohue</td>
<td>WRC</td>
</tr>
<tr>
<td>Dick Pasfield</td>
<td>OLW</td>
</tr>
<tr>
<td>Leith Bowyer</td>
<td>WRC</td>
</tr>
<tr>
<td>Brian Prince</td>
<td>OBP</td>
</tr>
<tr>
<td>ORIA Growers</td>
<td>N/A</td>
</tr>
</tbody>
</table>

5. **SURVEY & REPORT STRUCTURE**

The survey was designed to ensure both DAWA and OIC needs were met. Questions were formatted as a combination of multi-choice and open-ended questions. Eight key areas were explored as follows:

- **Grower Profile:** Growers were asked for information on the size and functions of their properties.

- **Perceptions (General):** Growers were asked a range of questions on their perceptions of a range of general water management issues.

- **Perceptions (Irrigation Practice):** Growers were asked questions on their perceptions of appropriate on-farm practices for their biggest water-using crop.

- **Knowledge:** Growers were asked to rate their level of understanding of environmental issues and solutions, and of a number of regional water management programs.
• **Irrigation Practice**: Growers were asked a series of questions to provide an indication of their actual on-farm practice, and of any limitations they experience in improving their on-farm practice.

• **Communication**: Growers were asked which communication mediums they would best respond to.

• **Farm Profitability**: Growers were asked to rate their current and future profitability, of limitations in improving farm profitability, and of what the DAWA can do to help with these issues.

• **Other Water Management Issues**: Growers were provided an opportunity to provide comments for any relevant ORIA water management organisations.

The Report structure follows a consistent format to that of the survey. Tables and graphs have been used were possible to demonstrate the collective results, supported with limited discussion outlining the results. No interpretation of the results has been provided as it is recognised that there are a number of audiences that may utilise the results, and it is appropriate to allow independent interpretation.

The report based on the sugar growers’ irrigation practices and perceptions about irrigation and sustainability utilises only the information gathered from the eight sugar growers who participated in the parent survey. This report can be read in conjunction with the “parent” report on the whole survey sample for comparison purposes.

### 6.1 GROWER PROFILE

Growers were asked a series of questions in relation to the size and nature of operation of their business in order to establish a profile of the survey participants, see Table 1.

**Table 1: Summary of Sugar Growers Profile.**

<table>
<thead>
<tr>
<th>Questions</th>
<th>Collated Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>How long have you been a grower in the Valley?</td>
<td>0.8-20yrs; Average 12 yrs</td>
</tr>
<tr>
<td>Approximately what area did you have under crop in the 2001/2002 growing season?</td>
<td>69-approx 1000 ha Average 448 ha</td>
</tr>
<tr>
<td>For the total water allocation for your property which crop type used the greatest proportion of that water in the 2001/2002 season?</td>
<td>Sugar 8</td>
</tr>
<tr>
<td>Which crop covered the greatest area on your property in the 2001/2002 season.</td>
<td>Sugar 6 Cucurbits 1 Other 1</td>
</tr>
<tr>
<td>Which crop returned the highest income in the 2001/2002 growing season?</td>
<td>Sugar 5 Cucurbits 1 Horticulture 1 Other 1</td>
</tr>
<tr>
<td>What type of irrigation system do you use? (Note: combination is more than one system used on the property).</td>
<td>Flood 5 Combination 3</td>
</tr>
</tbody>
</table>

### 6.2 GENERAL PERCEPTIONS

#### 6.2.1 Do you think it is important that environmental impacts caused by irrigation in the ORIA are addressed?

100% of survey participants stated that it is important that environmental impacts caused by irrigation in the ORIA are addressed.
6.2.2 Why do you think it is important environmental impacts caused by irrigation are managed in the ORIA?

25% of survey participants thought that it is important to manage environmental impacts to ensure that irrigation can continue in the ORIA into the future. 25% of survey participants thought irrigation impacts should be managed to ensure that the natural environment is protected. 37% of survey participants thought that impacts should be managed for both these reasons. 13% thought other issues independently were important. Other issues identified included:

- Develop enthusiasm
- Farmers not doing the right thing
- Because we are accountable for our actions
Figure 1: Perceptions of why it is important to manage environmental impacts caused by irrigation in the ORIA.

6.2.3 What do you think is the most important environmental issue affecting the ORIA that water management organisations and growers should be focusing on right now?

37% of survey participants thought the quality of drainage water discharged back to the Ord River was the most important environmental issue. 24% of participants thought that soil health management issues were most important; 13% of survey participants thought groundwater recharge was most important, 13% or that water allocation was the most important environmental issue; and 11% thought that weeds were the most important issue.
6.2.4 Are you interested in changing your farm management practices to help contribute to addressing environmental issues in the ORIA?

100% of survey participants stated that they were interested in changing their farm management practices to help address environmental issues in the ORIA.

6.2.5 Which water management organisations do you think should be leading the process of improving irrigation management practices in the ORIA?

No cane grower identified only one organisation to lead improved irrigation management practices in the ORIA. The most frequently identified organisation was the OIC – with 5 out of 8 growers identifying the OIC as being responsible in collaboration with, at least, one other organisation.

Figure 3 is based on the frequency of growers identifying organisations that they thought had a role rather than leading the process. 60% of the organisations identified in being a leader in improving irrigation management practices in the ORIA was OIC.
Figure 3: Perceptions of which water organisations should be leading the process of improved irrigation practices.

6.2.6 What do you think the next 10 years holds for agricultural businesses of the ORIA.

This question was open ended and as such there were a variety of responses. Each of the 8 responses from cane growers have been summarised and classed into categories, as follows:

**Business:**
- Good – positive
- Reasonable future – probably a few highs and lows
- Much of the same
- Higher input costs.

**Industry:**
- Dynamic – crop types come and go
- Sugar will go because of the misconception of the extent of its impact on the environment.
- Sugar cane will go, replaced by tree crops that are just as bad environmentally.
- Pretty average if the sugar industry collapses as so many jobs dependent on the mill.
- Future is bad if sugar cane collapses. If sandalwood locks up land, major impact on the region.
- If sandalwood takes over and locks up land for a long period then this is going to have a major impact on all industries including government and water management agencies.
- Depends on Stage 2 – if yes then more horticulture and sugar; if no then more sandalwood and less opportunity.

**Environmental Issues:**
- Higher environmental pressure

6.3 PERCEPTIONS: PRACTICE
6.3.1
This section relates to the irrigation practice for survey participant’s primary crop in terms of their overall water use. Table 2 summarises the responses for the following questions.

**Part 1:** How much water do you think this crop requires per hectare in an average season?
**Part 2:** How many irrigations do you think the mature crop requires in an average season?
**Part 3:** What do you think is the best irrigation interval for this crop in an average season?

It is important to note that participants identified a range of factors that would influence the answer they provided to the above three questions, such as the type of season, the type of soil and the age of the crop. This was particularly evident for Part 3 to the extent that the results were highly variable, and as a result has not been presented in this report.

Table 2: Summary of perceptions of correct practice for primary water using crop.

<table>
<thead>
<tr>
<th>Crops (no)</th>
<th>Water Use</th>
<th>No of Irrigations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>3: Don’t Know</td>
<td>8: Range 8-20</td>
</tr>
<tr>
<td></td>
<td>5: Range 20-29 Ml</td>
<td></td>
</tr>
</tbody>
</table>

6.3.2 For an average watering to your primary water using crop what percentage of water do you think:
- Is used by the crop;
- Leaches through to the groundwater table; and
- Is tail water and drains off farm?

One grower stated that he did not know the answer to this question and was not prepared to express an estimate of water use. Of the remaining 7 cane growers, the average for perception of water use by the crop was 55%. The average for perception of losses to groundwater, and to tail water, were 10% and 35% respectively.

Table 3: Perceptions on destination of water applied to primary water using crops.

<table>
<thead>
<tr>
<th></th>
<th>Used by Crop %</th>
<th>Ground Water %</th>
<th>Tailwater %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>30%</td>
<td>5%</td>
<td>15%</td>
</tr>
<tr>
<td>Maximum</td>
<td>80%</td>
<td>30%</td>
<td>60%</td>
</tr>
<tr>
<td>Average</td>
<td>55%</td>
<td>10%</td>
<td>35%</td>
</tr>
</tbody>
</table>

6.3.3 What would influence you to apply water to your crops?
- Visual assessment;
- Physical assessment of soil moisture;
- As per a regular scheduling program;
- As per agency recommendations;
- To link in with herbicide / pesticide management; and
- To link in with your fertiliser management.

100% of survey participants stated that a visual assessment of their crop, their chemical applications and fertiliser applications would influence them to apply water. Secondary to this was a physical assessment of crops influencing water regimes with 88%. Slightly less again were according to their schedule and Agency recommendations. To a lesser extent, 75% survey participants followed a regular schedule, and 75% acted on agency recommendations.

Figure 4: Factors influencing watering regimes.
6.3.4 What is the most influential factor in you applying water to your crops.

As the sample size of cane growers was quite small, it was difficult to determine trends as to what was important. Visual assessment was identified as a major contributing influence in 50% of responses. Of note is the interaction between physical, visual and scheduling.

Figure 5 Most influential factor in watering

6.4 KNOWLEDGE

6.4.1 How do you rate yourself in your understanding and knowledge of the following:
- Environmental issues and solutions of the ORIA; and
- A range of locally relevant water management programs.

The majority of survey participants thought that their understanding of environmental issues and on farm solutions was average. No participants rated their understanding as low for either environmental issues or solutions.
Table 4: Understanding / Knowledge of environmental issues and solutions.

<table>
<thead>
<tr>
<th></th>
<th>High</th>
<th>Average</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental Issues</td>
<td>1</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Environmental Solutions</td>
<td>2</td>
<td>6</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 5 demonstrates that the majority of survey participants had an average to low understanding of locally relevant water management programs. It is important to note that these programs have different purposes, different intended target audiences, different grower involvement and are at different stages of implementation.

Table 5: Understanding / Knowledge of water related programs.

<table>
<thead>
<tr>
<th>Program</th>
<th>High</th>
<th>Average</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>WRC Draft Ord River Water Allocation Plan</td>
<td>0</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>OIC Surface Water Licence Responsibilities</td>
<td>1</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>OIC Water Use Improvement Plan</td>
<td>1</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>DAWA Water Management Program</td>
<td>1</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>OLW Management Plan &amp; Projects</td>
<td>3</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Ord-Bonaparte Program &amp; Projects</td>
<td>1</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>
6.5 PRACTICE

6.5.1 As part of your farm management operations, do you currently or have you in the past undertaken any of the following practices to improve water use efficiency and/or manage groundwater? Which was the most successful?
(Note: Not all practices nominated were applicable to all survey participants' property functions.)

Table 6 demonstrates that there have been high participation rates in a range of improved farm practice techniques to address water use and groundwater management. However, the survey results do not show the extent, frequency or duration of participation, and thus participation levels demonstrated are indicative only. Other farm practices identified by survey participants included installing tailwater traps, biological farming and the use of soil moisture monitoring equipment.

Changing siphon size, and other practices were considered the most successful. Two survey participants did not know what was the most successful option, and did not provide comment.

<table>
<thead>
<tr>
<th>Practice</th>
<th>No. of Responses</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser leveling</td>
<td>8</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Considered changing irrigation system</td>
<td>7</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Change farm layout</td>
<td>8</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Use of flocculants</td>
<td>8</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Match siphon size to field run length</td>
<td>8</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Change scheduling of water</td>
<td>8</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Informal monitoring of permeability of blocks</td>
<td>8</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Informal monitoring of tailwater</td>
<td>8</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Other</td>
<td>8</td>
<td>2</td>
<td>6</td>
</tr>
</tbody>
</table>

The strategies identified by growers who answered “Yes” to Other were
- Soil moisture monitoring and recycling tailwater
- Maintaining infrastructure on-farm and soil moisture monitoring.

The most successful strategies identified by the survey participants were:
- Visual assessment
- Physical test of soil
- Matching siphon size to paddock length, and changing no. of siphons
- Don't know
- Scheduling & siphon size
- Combination of all - varies from field to field
- Using flocculants
- Changing system to trickle.

6.5.2 As part of your farm management operations, do you currently or have you in the past undertaken any of the following practices to improve the quality of tail water draining off of your farm. Which was the most successful?
(Note: Not all practices nominated were applicable to all survey participants' property operations.)
Table 7 demonstrates that there have been generally high participation rates in a range of improved farm practice techniques to address tail water quality. However, similar to question 6.5.1, the survey results do not show the extent, frequency or duration of participation, and thus participation levels demonstrated are indicative only. Other farm practices identified by survey participants included growing weeds as cover crops, pumping tail water back onto the block and increasing organic material in the soil.

When it comes to identifying the best on farm strategy for water draining from the farm, half the survey participants did not know which was best. Figure 7 indicates the range of participants’ responses.

Table 7: Participation in practices to improve tail water quality draining off-farm.

<table>
<thead>
<tr>
<th>Practice</th>
<th>No. of Responses</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of cover crop in wet season</td>
<td>6</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Tailwater Traps</td>
<td>8</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Bury Fertiliser</td>
<td>8</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Use of alternative fertilisers</td>
<td>8</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Chemical/fertilizer training</td>
<td>8</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Integrated Pest Management</td>
<td>1</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Use of soft chemicals</td>
<td>1</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>0</td>
<td>8</td>
</tr>
</tbody>
</table>

Figure 6 Most successful strategy for improving tailwater quality.

6.5.3 Do any of the following limit you in attempting to achieve improved water management practices on-farm?

Lack of time and lack of access to technical support were considered the most limiting factors for the sugar survey participants. Lack of knowledge and inability of the business to pay for the change were also considered as limiting.

Table 8: The limiting factors to improve on-farm practices.

<table>
<thead>
<tr>
<th>Knowledge to adopt</th>
<th>Maybe</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>
Lack of access to technical support | 0 | 5 | 3
Business ability to pay for changes | 1 | 4 | 3
Lack of time | 0 | 5 | 3
Other | 0 | 3 | 5

SUGAR GROWERS WHO IDENTIFIED OTHER LIMITING FACTORS STATED THE FOLLOWING INFLUENCES.

- Having land out of production
- Lack of confidence that supports improvement recommendation & that some options conflicting good for one problem but bad for another
- Lack of good technology to support change on farm.

6.6 COMMUNICATION

6.6.1 Which of the following types of communication would you respond to?

Fields trips were the greatest supported form of communication with all participants responding 'Yes' or 'Maybe'. The least supported was internet, web, e-mail extension with 50% of survey participants answering 'No'.

Supplementary comments provided by participants shows that they are more likely to respond well to communication mediums if they are brief, relevant and are coordinated to suit farm work schedules. Additionally, the need for credible professionals to coordinate training or fields days was raised.

<table>
<thead>
<tr>
<th>Table 9: Best supported communication mediums.</th>
<th>Maybe</th>
<th>Yes</th>
<th>No</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posted or faxed information</td>
<td>2 4 2</td>
<td>1: Short, relevant and simple 1: Depends on subject</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grower meetings</td>
<td>4 3 1</td>
<td>1: Must be relevant 1: Must be efficient 1: Too many, not useful</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field trips</td>
<td>2 6 0</td>
<td>1: Depends who goes 2: Must be relevant 1: Depends on timing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internet; web or e mail</td>
<td>3 1 4</td>
<td>1: Maybe for some</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Targeted group training days</td>
<td>3 3 2</td>
<td>3: Must be relevant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>On site technical support and training</td>
<td>2 2 4</td>
<td>1: Must be personable, well informed, local, professional, no bias 1: Must be good value for money 1: Too time consuming</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6.7 PROFITABILITY / STRATEGIC VIEWS

6.7.1 How do you rate last year's season?

Participants provided a balanced response in rating the profitability of their growing season last year.

Good 2; Average 3; Poor 3.
6.7.2 How do you expect your growing season to be this year?

Participants responses indicated that they are more optimistic about their potential profitability for the 2002/2003 growing season.

Good 1; Average 3; Better 3; Poor 1.

6.7.3 What four issues do you think are limiting the long term profitability of farms in the ORIA?

A wide range of issues that could limit the long term profitability of farms of the ORIA was identified. The 8 survey participants identified 26 issues that could affect the long term profitability of farms in the ORIA. The responses to this question have been grouped and summarised within the following themes:

Resources/Environment
- Water allocation.
- Water quality.
- Disease pressure.
- Pest pressure.
- Seasonal constraints on crops.
- Seasonal variations.
- Challenge of sustainability - environmental pressure.
- Increasing environmental responsibilities.

DAWA support
- Access to good research.
- Proven agronomic knowledge.
- Agronomic knowledge of how to manage cover crops.

Business Operational Issues
- Increasing costs of production.
- Cost of water.
- Poor commodity prices.
- Staff management issues, farmers need to manage staff better, to ensure they can have a good reliable workforce.
- Access to labour.
- The challenge in implementing BMP on-farm.
- Uncertain prices – variable.
- World prices of sugar.

Land Issues
- Availability of land and cost.
- Availability of land at reasonable prices.
- More land for sugar development.
- The likely loss of the local sugar industry.
- Land prices too high for the capacity of the grower, community to pay for the loss of expansion.
- There is not the right enterprise type for the Ord.
- Not having a world traded broad acre crop to grow.
6.7.4 *What can the Department of Agriculture do to help with these issues?*

**THE 8 SURVEY PARTICIPANTS RAISED 12 ISSUES. THE RESPONSES HAVE BEEN GROUPED UNDER FIVE BROAD THEMES.**

**Approach to Research**
- More proven technical information made available, particularly on disease management and biological farm management.
- Undertake specific research that is initiated by growers - growers must be allowed drive the process.
- Relevant research is needed.
- Keep doing that R&D role.
- Look within, self evaluation and resultant improvement.

**Knowledge**
- Provide good quality agronomic staff who know what they are talking about.
- They are under resourced and thus have limited technical capacity.
- There is a lack of expertise for area and industry.

**Business/Regional Support**
- Get more land released and quickly.
- Keep sugar industry alive.
- Maybe a role in helping with water pricing.
- Keep playing that emergency role we need in the district - if there is a crisis such as a plague - DAWA can come in and lead growers through that process.

**6.8 CLOSE**

**6.8.1 Are there any other comments you would like to raise with water management organisations in the ORIA?**

This was an open ended question and as such each participant's response has been listed by broad theme. Figure 7 shows the breakdown by percentage of these broad themes.

**Water Management Agency Co-ordination Issues**
- We don't know who is doing what - roles and responsibilities
- Do not really understand the roles of all these water agencies - and who is doing what
- Concerned that there is doubling up
- There are major inter and intra agency problems - that being they are not working together, which limits capacity to make decisions
- Roles and responsibilities not defined - people often going where not required
- Difficult to understand which agencies are doing what - its confusing
- Proactive: Agencies must be more proactive and get things done

**Research**
- Knowledge gaps must be addressed
- Quick easy solutions must be progressed
- Pesticide project is trick as it deals with issues of today - things will change in time - but we can only deal in real time
• Issues with science - in that it lacks per review with growers - often incorrect - treats growers like idiots - and often represents or bias to an agenda - fails to support be open and lateral in approach
• I would lie to see enviro scan help other people - should be through out the district

Resources/Environment
• Priority of drainage re-use system as opposed to wetlands systems as re-use systems will result in groundwater recharge
• Concern about the impact of effluent discharge (health risk and cost to farmers)
• Time to stop talking about land releases - time to take action so that farmers can have certainty about the future

Other
• No one has the courage top take a stand and make hard decisions which need to be made to progress the region
• Concerned about key local people getting burnt out by being involved in these agency / community activities - I want to establish myself before I get involved
• Like to see a stronger role for KPI - more of an advocacy role - but with broad representation for growers
• There needs to be an umbrella group with a CEO and case officers for each key crop type - environmental approach would be broader across crop type.
• Each key agency would be represented
• It all needs to be centralised / integrated / coordinated - it is not this at the moment.
Executive Summary

Irrigation practices have changed since the benchmarking survey was conducted under project CSR002 1996 to 2002. This survey reported an average water application per crop of 40ML (range 20 to 80) per hectare with an average of 27 irrigations (range 15 to 42). Total water use, number of irrigations, and timing of irrigations have been substantially and favourably modified according to this survey.

A second, limited, survey reported in August 2003 indicated an application range of 20 to 29 ML with 8 to 20 irrigations. This 2004 survey reports an average of 21ML per hectare (range 13 to 30) with 16 irrigations (range 10 to 21).

Changes in the approach to scheduling have been well received by growers, as has the supporting extension activities funded by this project.

Introduction

SRDC Project CSE007 has now been running in the Ord River Irrigation Area since 2002. The project objective is to build capacity in the irrigating community to save water and to reduce rising water tables. Extension activities by Bill Webb provide a mechanism by which sugar growers can seek advice, improve their knowledge base and apply irrigation best practice in the growing of sugar cane.

The survey questions were initially developed by Bill Webb, and later modified with input from Geoff Inman-Bamber, Tracy Henderson, and Francis Bright. The survey contained 20 questions of which 8 were Yes/No questions, 7 were tick-a-box questions and the remainder interpretative questions.

The survey was hand delivered to growers. The majority of growers opted to complete the survey immediately, while others either posted or faxed the completed survey to the Department of Agriculture, Kununurra.

This document provides
A summary of the survey results,
An interpretation of survey question answers, and
Recommendations for improving irrigation management capacity building based on the results of the survey.
Results
Survey respondents and farmer details.

Twelve growers/managers on 16 farms out of a total of 20 farms had the opportunity to participate in the survey. No selection process was employed. Growers were invited to participate on the basis of opportunity during Bill Webb’s day to day activities.

The surveyed farms covered 95.4% of the total area under sugar cane in the ORIA (3 848 hectares surveyed out of 4 032 hectares under sugar cane).

The range of the area of sugar managed by each survey respondent was 41 - 690 hectares with a mean of 380 and a median of 455 hectares.

Experience in years of growing sugar ranged from 2 to 44 years with a mean of 13.42 and a median of 9.5 years. The sugar industry in the ORIA has been in existence since 1995. The high mean value, greater than the number of years that the industry has been present in the ORIA shows that there are growers who have had previous experience with sugar cane growing in other areas.

Question 1 – Grower Awareness of Project

![Aware of Project](image)
**Question 2/2A** – On Farm Involvement in Project and in what capacity.

**Project Involvement**

- **Yes**: 75%
- **No**: 25%

**Type of involvement**

- Monitoring site: 6
- Advice: 2
- Trial: 2
- Other: 2
Question 2B/2C – Involvement generating new types irrigation information

New information generated by project?

<table>
<thead>
<tr>
<th>Improved knowledge</th>
<th>Number of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil water</td>
<td>7</td>
</tr>
<tr>
<td>Crop water use</td>
<td>8</td>
</tr>
<tr>
<td>When to irrig</td>
<td>8</td>
</tr>
<tr>
<td>no. of irrigs</td>
<td>8</td>
</tr>
<tr>
<td>Monitor growth</td>
<td>7</td>
</tr>
</tbody>
</table>
**Question 3** – Use of extension service for irrigation management

![Use of Extension Service](image)

**Question 4/4A** - Has your frequency of irrigation changed, and frequency information

Changes in Frequency of watering - Yes = a reduction in the number of irrigations. How many times do you irrigate your sugar cane blocks?

![Changes in Watering](image)

<table>
<thead>
<tr>
<th>Number of times</th>
<th>Maximum</th>
<th>Average</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent No Answer</td>
<td>58.3 (7)</td>
<td>33.3 (4)</td>
<td>58.3 (7)</td>
</tr>
<tr>
<td>Of those who answered</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max</td>
<td>22</td>
<td>20</td>
<td>17</td>
</tr>
<tr>
<td>Min</td>
<td>14</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>Mean</td>
<td>18.4</td>
<td>15.75</td>
<td>13.4</td>
</tr>
<tr>
<td>Median</td>
<td>19</td>
<td>15.5</td>
<td>12</td>
</tr>
</tbody>
</table>

**Question 5** Amount of water used
Question 5A/5B  Application rates per season and per watering

**Water use since project started**

<table>
<thead>
<tr>
<th></th>
<th>More</th>
<th>Less</th>
<th>Same</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum</td>
<td>1</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Average</td>
<td>9</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Minimum</td>
<td>9</td>
<td>7</td>
<td>9</td>
</tr>
</tbody>
</table>

**Total water use per hectare applied in a season (Ml)**

<table>
<thead>
<tr>
<th>For those who estimated water use</th>
<th>Maximum Water Used</th>
<th>Average Water Used</th>
<th>Minimum Water Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest</td>
<td>30</td>
<td>28</td>
<td>16</td>
</tr>
<tr>
<td>Lowest</td>
<td>23</td>
<td>17</td>
<td>13</td>
</tr>
<tr>
<td>Mean</td>
<td>26.3</td>
<td>21</td>
<td>14.3</td>
</tr>
<tr>
<td>Median</td>
<td>26</td>
<td>20</td>
<td>14</td>
</tr>
</tbody>
</table>
Water use per hectare applied per irrigation *

<table>
<thead>
<tr>
<th></th>
<th>Maximum</th>
<th>Average</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest</td>
<td>2.00</td>
<td>1.90</td>
<td>1.38</td>
</tr>
<tr>
<td>Lowest</td>
<td>1.41</td>
<td>1.00</td>
<td>0.75</td>
</tr>
<tr>
<td>Mean</td>
<td>1.67</td>
<td>1.32</td>
<td>1.01</td>
</tr>
<tr>
<td>Median</td>
<td>1.6</td>
<td>1.3</td>
<td>0.9</td>
</tr>
</tbody>
</table>

* If twer to question 5A (total Ml used) is divided by the answer to question 4A (number of irrigations), the means and medians are in good agreement i.e.

<table>
<thead>
<tr>
<th></th>
<th>Maximum</th>
<th>Average</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1.53</td>
<td>1.33</td>
<td>0.98</td>
</tr>
<tr>
<td>Median</td>
<td>1.63</td>
<td>1.29</td>
<td>1.17</td>
</tr>
</tbody>
</table>
**Question 6** Factors influencing the number of irrigations

Eighty percent of growers who answered this question rated rain as having the greatest influence on the number of irrigations.

"The Project" was marginally next most popular, with "infrastructure" the least.

Three growers refused to prioritise the list, stating simply in the "other" choice that they applied "what the crop required". One wonders how this answer would have rated if it was included in the list.

![Factors Influencing the Number of Irrigations](image)

**Question 7** – Factors influencing the decision of when to irrigate.

![Deciding when to Irrigate](image)
**Question 8/8A** – Awareness of the Impact of furrow irrigation on ground water levels, and any change in management to reduce the impact.

**Effect of furrow irrigation on soil water table**

<table>
<thead>
<tr>
<th>Yes</th>
<th>No</th>
<th>No Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>92%</td>
<td>0%</td>
<td>8%</td>
</tr>
</tbody>
</table>

**Different practices used**

<table>
<thead>
<tr>
<th>Less water</th>
<th>Monitor tailwater</th>
<th>Laser level</th>
<th>Siphon size</th>
<th>Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**Question 9/9A** – Grower use of APSIM generated Irrigation Scheduling Tables

**Consulting Schedule tables**

- Constantly
- Most of the time
- Some of the time
- Never
**Question 10/10A/10B** – Prediction of irrigation times using real-time information and best means of communication of information.

Prediction of irrigation times

Would irrigation predictions be useful?

- Yes: 92%
- No: 8%

Preferred means of communicating real-time scheduling information

<table>
<thead>
<tr>
<th>Method</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phone</td>
<td>10%</td>
</tr>
<tr>
<td>E-mail</td>
<td>20%</td>
</tr>
<tr>
<td>ABC Radio</td>
<td>10%</td>
</tr>
<tr>
<td>UHF Radio</td>
<td>10%</td>
</tr>
<tr>
<td>Internet</td>
<td>10%</td>
</tr>
<tr>
<td>Fax</td>
<td>50%</td>
</tr>
</tbody>
</table>

**Other Grower Comments**

This section allowed growers to make any comments that they wished. Three respondents answered this question with the following comments.

- Re Q's 4 & 5, I have increased frequency during warmer months and reduced during cooler months as a result of enviroscan and agronomist advice
- To help with water use more and easier info from OIC about actual water delivered to farm
- Bill is very approachable & always willing to help

**COMPARISON WITH PRE-PROJECT SURVEY**

*Information extracted from Final Report on SRDC Project CSR022*
Best practice irrigation management to maximise profitability and ensure sustainability in the Ord Sugar Industry

"Water for irrigation is abundant and relatively cheap in the ORIA and the survey showed that growers applied an average of 40ML ha⁻¹/crop in 27 irrigations in these long season cane crops (with a range of 20 to 80ML ha⁻¹/crop in 15 to 42 irrigations)."

A second, limited, survey reported in August 2003 indicated an application range of 20 to 29 Ml with 8 to 20 irrigations. This compares with the current survey average of 21 ML ha⁻¹/crop in 16 irrigations (range 13 to 30ML ha⁻¹/crop in 10 to 21 irrigations)

RECOMMENDATIONS

* That grower friendly information on irrigation water volumes be readily available.

Commonly mentioned by growers was the fact that information on water use (volumes) was not readily available. OIC manager Andy Kelly was approached with the question. Andy maintains that the information IS fed back to growers, but they chose not to apply the necessary analysis time to the data.

Are growers really interested while the cost of water remains as low as it is?

Could the data be made available in a more "grower friendly" format?

This issue should be pursued with growers and OIC.

* That the project proceed to further fine-tune tools for real-time scheduling of irrigations, and that as many communications methods as possible be employed to get this information to growers.

* That growers continue to be encouraged through the Extension service to seek ways to minimise the off-site impact of irrigation by improving application efficiency.

CONCLUSION

Growers are aware of the project and are keen to support it. Whilst some confusion has been generated in the past by research results, growers are aware that the project is making progress towards best practice irrigation management.

While the research effort is refining recommendations and tools, growers are acutely aware of, and supportive of, the project through the extension activity funded by the project.
APPENDIX 3
SURVEY OF IRRIGATION PRACTICE AND ATTITUDES IN THE ORIA SUGAR INDUSTRY - JANUARY 2006

Appendix 3a
Survey of Irrigation Best Practice

For the 2006 survey, a number of questions related to irrigation best practice were added to the survey (Appendix 1). These questions were adapted from the Compass workbook, and scored as in Compass, so that some comparisons can be made with scores obtained from Compass participants in the Eastern states’ Sugar Industry.

Growers scored highest in the area of soil health (question 11e) with an average of 1.38 out of a worst possible 4 (Figure 1). This reflects local growers’ attitudes to the newly commenced SRDC Project WAA003, assessing new farming systems in the ORIA.

Attitudes to recycling tailwater rated 1.88 out of a worst possible 4, reflecting growers recognition of the potential environmental damaging effects of excess tailwater removing chemicals, fertilisers, and soil, off site. It is also a reflection of growers attitudes to minimising the total amount of irrigation water applied to their cane blocks, and the potential for deep drainage (see Figures 15, 16 in Appendix 6).

Growers also scored well with their attitudes towards scheduling irrigations. The worst result was in the area of farm planning. Only one grower, who has a land and water management plan, had other than a current mill map from which to plan their management decision making.

In terms of individual growers, four of the eight respondents averaged less than a score of two across all questions. No grower averaged higher than 2.5 (Figure 2).

It will be interesting to compare these scores with those obtained from Eastern states growers, but indications are that ORIA growers already have a high degree of awareness of environmental management as it relates to their business.

![Irrigation Best Practice Scores - 2006 Survey](chart.png)

**Figure 1 – All Respondents’ Mean Irrigation BP Scores (1=best, 4=worst)**
In Question 12 of the 2006 survey, growers were asked the question:

“If irrigation best practice was able to be fully implemented, what benefits do you envisage would be derived in terms of lifestyle, profitability and the environment?”

Their comments are reproduced below.

* Reduced water table, reduced chemical and fertiliser runoff

* If level furrow irrigation works well we will be able to expand the sugar industry more easily because 1/ irrigation cost will decrease 2/ less water 3/ have very little irrigation runoff (none)

* Less work, higher profitability, healthier crop and improved environment

* I think everyone has a desire to use best practice

* Time efficiency, lower crop production costs, decrease ground water

* If irrigation could be fully automated, you wouldn’t mind growing it *(sugarcane)*

* Two of the eight growers offered no comment
## Compass Score for Question 11 - lower number = better practice

<table>
<thead>
<tr>
<th>Grower #</th>
<th>11a</th>
<th>11b</th>
<th>11c</th>
<th>11d</th>
<th>11e</th>
<th>11f</th>
<th>Tot. Score</th>
<th>Mean Score</th>
<th>Grower comment</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>14</td>
<td>2.33</td>
<td>Reduced water table, reduced chemical and fertiliser runoff</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>10</td>
<td>1.67</td>
<td>If level furrow irrigation works well we will be able to expand the sugar industry more easily because 1) irrigation application cost will decrease 2) less water will be used per irrigation and in total 3) there will be little or no runoff from irrigation</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>11</td>
<td>1.83</td>
<td>Less work, higher profitability, healthier crop and improved environment</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>15</td>
<td>2.50</td>
<td>I think everyone has a desire to use best practice</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>11</td>
<td>1.83</td>
<td>No comment</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>14</td>
<td>2.33</td>
<td>Time efficiency, lower crop production costs, decrease ground water</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>14</td>
<td>2.33</td>
<td>No comment</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>10</td>
<td>1.67</td>
<td>If irrigation could be fully automated, you wouldn't mind growing it (sugarcane)</td>
</tr>
</tbody>
</table>

Means 2.00 2.38 2.00 1.88 1.38 2.75 12.38 2.06

<table>
<thead>
<tr>
<th>Question</th>
<th>High score</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>11a</td>
<td>4</td>
<td>Scheduling method</td>
</tr>
<tr>
<td>11b</td>
<td>4</td>
<td>When to start irrigating</td>
</tr>
<tr>
<td>11c</td>
<td>3</td>
<td>Minimising deep drainage</td>
</tr>
<tr>
<td>11d</td>
<td>4</td>
<td>Recycling tail water</td>
</tr>
<tr>
<td>11e</td>
<td>4</td>
<td>Soil health</td>
</tr>
<tr>
<td>11f</td>
<td>4</td>
<td>Farm plan</td>
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<tr>
<td>Total</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td></td>
<td>184</td>
<td></td>
</tr>
</tbody>
</table>
Appendix 3b  
Results of 2006 Grower Survey conducted for CSE007  
Bill Webb, March 2006

In my opinion, the majority of growers have accepted outcomes of the project, and attitudes towards environmental issues associated with irrigation are positive. There has been growing user confidence in irrigation related advice offered.

Since the last survey, the number of cane farm management units in ORIA has reduced from 18 to 12. Eight of the remaining units are included in this survey (67%). These growers represent 97% of the total area under cane for 2006 harvest compared with 75% of respondents representing 95% AUC in 2004.

Project awareness
More growers claim awareness of the project than in 2004, and more growers have become involved with the project since that time (Figures 1 and 2). Documented grower activities in the project include using the irrigation web service ‘WaterBalance’, hosting monitoring sites, growth measurements and seeking specific irrigation advice. One participating grower is a co-author of a paper reviewing the extension activities of the project (Webb, Inman-Bamber and Mock 2006). Several growers attended the workshops held each year in March and November. Additionally, in 2006, 100% of growers claimed to have improved their irrigation knowledge through involvement with the project compared to 75% in 2004 (not presented).

![Figure 1 - Grower awareness of the project](image-url)
Question 2 - Grower Involvement in Project

![Graph showing grower involvement in the project]

Figure 2 - Grower involvement in the project

Question 2C - In what area/s has your knowledge increased?

![Graph showing areas where grower knowledge has increased as a result of the project]

Figure 3 - Areas where grower knowledge has increased as a result of the project
**Increased knowledge**

The main areas of increased knowledge nominated by growers are contained in Figure 3. The project was rated highly (second only to rain) by growers in influencing their irrigation management decisions (Figure 4). Influence of the project on irrigation management has doubled since 2004. Advice on irrigation management from the agronomist was rated second only to the growers' own experience (Figure 5). Almost 90% of growers have sought irrigation specific advice from the agronomist compared to 75% in 2004 (Figure 6).
Irrigation management

There are few marked differences in respect to irrigation number and amount between the responses in this survey and the last in 2004. For instance growers are still largely not recording the number and amounts of individual irrigations. Despite this, estimates by growers who answered these questions were very similar to those recorded in 2004. Most confirmed they use less water now than they did before the project commenced (Figures 7 to 11). Answers to questions 4a, 4b, 5a and 5b indicate acceptable consistency in the answers.
Question 5 - Do you use more or less water than prior to the Project’s commencement in 2002?

![Bar chart showing the percentage of respondents using more, less, or the same amount of water in 2004 and 2006.]

Figure 8 – Influence of project on irrigation amount

Question 5A - How many Megalitres do you apply on sugarcane for a season?

![Bar chart showing the maximum, mean, and minimum amounts of water applied in 2004 and 2006.]

Figure 9 – Irrigation volume used annually on a hectare of sugarcane
Question 5B - Megalitres per hectare applied at each irrigation

Figure 10 – Irrigation volume used per irrigation on a hectare of sugarcane

Question 4A - How many times do you irrigate your sugarcane blocks?

Figure 11 – Number of irrigations used annually on a block of sugarcane
Use of “in-ute” guide

In 2004, growers had access to a model generated “in ute” guide to irrigation scheduling intervals. The 2004 survey indicated that some growers were using this guide (Figure 12). In 2006, 50% of growers indicated that they still referred to this guide occasionally (Figure 13).

Figure 12 – Use of the irrigation scheduling tables in 2004

Figure 13 – Use of the irrigation scheduling tables in 2006
Acceptance of real-time scheduling

A change in direction of the project was accepted by growers who have adopted the new scheduling system based on real-time calculated daily crop water use. In 2004, growers were aware of the proposed new system, and 92% indicated they would use real-time scheduling if they had access to the information. In 2006, 75% growers indicated that they actually were accessing and using the real-time scheduling information.

There was a somewhat marked change in the preferred method of delivery of scheduling related information, reflecting the growers increased use of internet based tools eg WaterBalance (Figure 14).
Environmental concerns

Relating to concern over the potential for furrow irrigation to impact on ground water levels, growers again demonstrated their awareness (Figure 15). Compared to the 2004 survey, an increased number of growers have taken action to minimise their potential impact on ground water (Figure 16). Some of the tactics nominated by growers included laser levelling; channel and drain maintenance; manipulating siphon size and number per shift; water only when required; managing tailwater time; minimise water sitting in channels:

![Diagram](image1.png)

Figure 15 – Awareness of impact of furrow irrigation on the ground water table

![Diagram](image2.png)

Figure 16 – Action taken to reduce impact of furrow irrigation on the ground water table
APPENDIX 4

Crop coefficients and irrigation requirement for sugarcane in high temperature conditions
In preparation for Field Crops Research. Graphics and Tables are embedded for easier reviewing but will be removed to conform to FCR requirements before submission.

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APPENDIX 7

Daily water requirements for sugarcane in the Ord River irrigation area.

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Abstract

Irrigation is necessary to help meet the high demand for water by sugarcane in several countries including Australia and various countries in Africa. Crop coefficients (K_c) have been derived for tropical and subtropical conditions in Australia and Southern Africa. It is not known if these apply in extremely hot and arid conditions where sugarcane is grown under irrigation such as in northern Western Australia (Ord River). The objective of this paper was to derive K_c for the Ord River Irrigation Area to use these values to determine annual irrigation requirements for the Ord. Bowen ratio energy balance experiments showed that K_c for the rapid growth phase (K_cmid) in the Ord was about 1.0, which is lower than K_cmid for cooler and more humid climates. This arose because evapotranspiration (ET_c) from sugarcane did not exceed 8 mm d⁻¹ very often, whereas reference evaporation (ET_o) in these climates can often reach 8 mm d⁻¹. K_c for the developing canopy was derived directly from radiation and temperature to avoid using more complex algorithms. Cane yield was reduced when K_c=0.75 was used to schedule irrigation but no yield increase was achieved by increasing K_c to 1.25. High yields and reduced water use can be obtained in the Ord by using an initial K_c of 0.3 and a K_c of 1.0 applied after 80% canopy closure up to the drying-off phase. Soil water deficit can be determined from ET_o estimates and the suggested K_c regime with a precision that is close to the resolution of soil water monitoring using capacitance based measurement techniques.

Key words: Bowen ratio; Crop coefficient; sugarcane; evapotranspiration, irrigation scheduling; capacitance sensors

1. Introduction

Crop water use or evapotranspiration (ET_c = K_c ET_o) has been derived from crop coefficients (K_c) and reference evapotranspiration (ET_o) for many crops over many years (Doorenbos and Pruitt, 1977; Allen et al., 1998). Crop coefficients have been obtained mostly by field measurements but the theoretical basis is sound and variations in K_c can be explained by variations in crop height, stomatal and aerodynamic resistances (Pereira et al., 1996). Water demand from sugarcane is high compared to most other crops not only because of a comparatively high crop coefficient but also because of its sustained period of growth lasting from 10 to 24 months. A high crop coefficient is due to relatively low bulk stomatal and conductance (<60 s m⁻¹, Inman-Bamber and Smith, 2005) and to a crop height which can exceed 5 m. Irrigation is necessary to supply much of this demand in several countries including Australia and various countries in Africa. Crop coefficients (ratio of actual to reference evapotranspiration) have been derived for sugarcane in the Burdekin area in Australia and in Swaziland in
Southern Africa (Inman-Bamber and McGlinchey, 2003) where mean annual temperatures are 24 and 22 °C respectively. The crop coefficient after canopy closure (KcMID) was similar (1.23 for Burdekin and 1.30 for Swaziland) in these two regions (Inman-Bamber and McGlinchey, 2003) and one could expect that the results would apply to most of the irrigated sugarcane regions in Australia and Southern Africa where temperature and radiation conditions are similar (Inman-Bamber, 1995; Muchow et al., 1997). One irrigated sugarcane region in Australia, the Ord, stands out from the others in terms of temperature and radiation conditions. Mean annual temperature and radiation are 28 °C and 22.6 MJ d⁻¹ for Kununurra (15.65 S, 128.72 E) in the Ord Irrigation Area (ORIA) in northern Western Australia compared to 21 to 25 °C and 18.7 to 19.9 MJ d⁻¹ for irrigated production areas in Queensland (Muchow et al., 1997). The mean annual sugarcane demand for water in the ORIA was estimated at 2931 mm, 1502 mm in the Burdekin and less in other regions in Australia, by Robertson et al. (1997) using the APSIM-Sugarcane simulation model (Keating et al., 1999). A survey by Wood et al. (1998) indicated that the average water applied to cane crops in the Ord was 3250 mm per annum with values ranging from 1530 to 5380 mm. Muchow et al. (2001) conducted irrigation scheduling experiments and found that annualized gross irrigation could be reduced from 2957 to 2176 mm without affecting cane or sugar yield. A further reduction to 1723 mm, reduced yields only marginally. There is increasing concern in the ORIA that excessive use of water is leading to increases in ground water table height. Growers would like to reduce unnecessary labour as well as drainage and runoff from their farms and there is a need to determine more precisely the daily and annual water requirement for sugarcane in these extreme conditions.

Research was undertaken to determine if crop coefficients developed for the Burdekin and Swaziland (Inman-Bamber and McGlinchey, 2003) could be applied to high temperature and radiation conditions of the ORIA. The research was carried out under the close scrutiny of Ord sugarcane irrigators. The participatory nature of this research led to the development of a web-based scheduling service for these growers (Inman-Bamber et al., 2006; Webb et al., 2006). The objective of the research reported in the current paper was to derive crop coefficients for the Ord and similar climates and to use these to determine daily and annual irrigation requirements for sugarcane in the Ord.

**Materials and Methods**

All experiments were conducted at the Frank Wise Institute (FWI) of the Dept. Agriculture, Western Australia (15.65ºS, 128.72ºE) on a Northern Ivanhoe Kununurra greyish cracking clay. Plant available water capacity for this soil is 129 and 190 mm to a depth of 1.0 and 1.9 m respectively (Plunkett and Muchow, 2003). All experiments were furrow irrigated from the ORIA scheme.

Establishment and irrigation of Bowen ratio experiments

9a

A Bowen ratio energy balance (BREB) system similar to the one described by Inman-Bamber and McGlinchey (2003) was installed in a third ratoon of cultivar Q99. The field was 400 by 580 m and the BREB was installed 25 m from the field boundary, downwind of the most common wind direction. The fetch exceeded 140 m in an arc of 200 degrees. The field was ratooned after harvesting on 17Sep03 and the BREB system was operational by 10Oct03 when the crop was 3 weeks old. Diammonium phosphate (200 Kg ha⁻¹) and Urea (400 Kg ha⁻¹) was applied soon after harvesting. Weeds were controlled with Gesapax Combi pre-emergent herbicide at 8 L ha⁻¹. Experiment 9a was scheduled using a system based on the APSIM sugarcane model calibrated for Ord conditions as described by Attard et al. (2003). The essential features of the calibration were an increase in transpiration use efficiency from 8.7 to 10.0 g kPa kg⁻¹ and a decrease in radiation use efficiency from 1.65 to 0.99 g MJ⁻¹ when more than 30 t ha⁻¹ biomass had accumulated in ratoon crops. The latter adjustments were necessary to account for repeated observations of reduced biomass accumulation in Ord crops after the wet season (Attard et al., 2003; Inman-Bamber et al., 2006).
A second BREB experiment (9d) was conducted on a first ratoon of Q95 harvested on 2 September 2004. Fertilizer application was as for BREB1. Gesaprim was applied at 3 kg ha⁻¹ and Stomp at $1 ha⁻¹ as a pre-emergent herbicides. The BREB system was installed on 16Sep04. Irrigation was scheduled as for the “Medium” irrigation treatment of the scheduling experiment described below.

11d
A third BREB experiment (11d) was conducted on a first ratoon of Q99 harvested on 5 May 2006. The Bowen ratio mast was installed midway along and about 30 m in from the NW side (downwind) of the >15 ha block of Q99 during 15-18 May 2006. Irrigation was scheduled as for the “Medium” irrigation treatment of the scheduling experiment described below.

The BREB installation and operation
The BREB system is described briefly below. Full details were supplied by Inman-Bamber and McGlinchey (2003). The system (Campbell Scientific, Inc. (CSI), Logan, UT, USA) consisted of a net radiometer (Q7.1, REBS, Seattle, WA, USA), five soil heat flux plates (HFT3, REBS) and two identical sensor arms each supporting an air intake through a 50 mm diameter, 1.0 μm pore filter and an aspirated fine wire chromel-constantan thermocouple. Air was sampled alternately from each arm every 120 s. This air was passed through a chamber, housing a dew point hygrometer (Dew 10, General Eastern Instruments, Woburn, MA, USA) and dew point was measured at 10 s intervals. The mean dew point temperature for the final 80 s of each sampling period was stored in a 23X data logger (CSI). Air temperature at the arms was also measured and logged every 10 s.

The arms were mounted on a movable frame surrounding a 6-m high mast made from 150 mm square aluminium section. A set of eight V-shaped wheels, aligned on the diagonal, held the frame tightly to the mast and allowed it to be winched up and down with minimal movement on planes other than the vertical. A standard arm height was adopted with the lower arm about 1.5 x canopy height and the upper arm about 1.5 m above the lower arm. The lower arm could be raised to nearly 6 m from the ground if necessary. The net radiometer was mounted on the frame at the height of the lower arm facing the opposite (downwind) direction. The arms and net radiometer were raised each week as the canopy height increased. The net radiometer level and condition of the domes were checked regularly by lowering the frame and arm assembly for a few minutes at a time. The dew point mirror was cleaned and reset each week.

The soil heat flux (SHF) plates were installed at a depth of 80 mm, equidistant across the 1.8 m furrow between crop rows. Thermocouples were installed at depths of 20 and 60 mm in two positions in line with SHF plates 2 and 4. Two frequency domain reflectometers (model CS615, CSI) were inserted horizontally, each spanning 25 to 60 mm soil depth and were scanned and logged every 20 minutes. A tipping bucket rain gauge (T.B.3; Hydrological Services, Warwick Farm, Australia) was mounted at the height of the lower arm and logged every 20 minutes.

Daily crop evapotranspiration (ETc) was determined only for days when more than 80% of the 20 min BREB data passed the acceptance criteria of Omura (1982) as described by Inman-Bamber and McGlinchey (2003). In addition, daily ETc was considered valid only when more than 80% of the 20-min readings were taken with wind in the right direction.

Radiation interception by the crop
Canopy development was measured in each BREB experiment by placing two 1 m long tube solarimeters end to end on the soil surface at an angle so as to span between two crop rows exactly. The solarimeters were first placed outside the field for a week in order to ensure that their mV outputs responded the same to variations in solar radiation. Two solarimeters remained fully exposed outside the field and FIR was obtained by dividing mV readings from the instruments in the crop by mV readings from the exposed solarimeters.

Reference evaporation
An automatic weather station (AWS, Campbell Scientific) was installed in an open grassed area about 2 km from the BREB installations. The AWS consisted of a tipping bucket rain gauge similar to one on the BREB
installation, an anemometer (RM Young Co. Traverse City, MI USA), a pyranometer; (Li 200x, Licor Inc, Lincoln, NE, USA) and a combined temperature and humidity sensor (HMP45ac, Vaisala, Helsinki, Finland). AWS data were used to determine daily reference evapotranspiration (ET\text{0}) from Allen et al. (1998, ‘FAO 56’). Full details can be seen in Inman-Bamber and McGlinchey (2003).

**Irrigation scheduling experiment**

A first ratoon crop of Q96 in a 7 ha field (Field 7b) at FWI was subdivided into 12 plots, each 14 rows wide and 220 m long. Rows were 1.83 m apart. Four irrigation treatments were allocated randomly to four plots in each of the three replicate blocks. The treatments were designed to test a range of possible crop factors (K\text{C}) for the Ord. All treatments were irrigated when the estimated soil water deficit was 60 mm. K\text{C} was the same for all treatments until estimated fraction of intercepted radiation (FIR) reached 0.6. During this period K\text{C} was assumed to be at least 0.2 and 25% greater than FIR in order to arrive at K\text{C} = 1.0 when FIR = 0.8. This assumption was based on the observation that K\text{C} reaches a maximum when FIR = 0.8 in BREB experiments in Queensland (Inman-Bamber and McGlinchey, 2003).

FIR was calculated as \( \text{FIR} = a(1.0 + \exp(b + cH)) \) where \( H = S_0 + 0.3((T_{\text{max}}+T_{\text{min}})/2 -7.0) \), \( S_0= \) incident solar radiation, \( T_{\text{max}} \) and \( T_{\text{min}} \) are maximum and minimum daily temperature and \( a, b \) and \( c \) are non-linear regression coefficients (Inman-Bamber et al. 2006).

K\text{C} was increased to 1.0 during rain or irrigation and was then reduced by 0.2 for each rainless day until K\text{C}=FIR \times 1.25. When FIR>0.6, a ‘Low’ irrigation treatment was irrigated using K\text{C} =0.75. When FIR>0.8, a ‘Medium’ treatment was irrigated with K\text{C}=1.00 and a ‘High’ treatment with K\text{C}=1.25. A ‘Variable’ treatment was irrigated with K\text{C}=1.00 until the crop was deemed to have produced 30 t ha\(^{-1}\) biomass at which point K\text{C} was reduced to 0.75. APSIM-Sugarcane was used to determine when the critical biomass was achieved.

### 3. Results

**Climate**

Rainfall in is highly seasonal in the Ord with distinct wet and dry seasons associated with the presence or absence of the tropical monsoon. The rainy (wet) season started in December in each of the three years of the study and it ended in March 2004 (9a03) and in April 2006 (11d05). The 9d04 experiment was terminated toward the end of the wet season in 2005 (Figure 1). Total rainfall during three experiments was 868, 608 and 1371 mm for 9a03, 9d04 and 11d05 respectively. Seasonal variation in monthly mean daily maximum and minimum temperatures was similar in each year with a seasonal maximum of about 40 °C in October and a minimum of about 14 °C in June (Figure 1).

![Figure 1. Cumulative rainfall, and monthly mean maximum and minimum daily temperature for the 9a (△—△), 9d (□—□) and 11d (○—○) experiments.](image)

**Leaf cover**
Simulated radiation interception was lower than measured interception during the first 2 months of development in each of the experimental crops (Figure 2). After 2 months simulated interception was lower than measured interception for 9a, was similar to measured interception for 9d, and it was slightly greater than measured interception in the 11d crop. Simulated and measured interception were similar in all crops after the latter reached about 80% which is when KC is expected to reach a maximum (Inman-Bamber and McGlinchey, 2003).

**Biomass and cane yield**

Before February biomass accumulation in the 9a crop was slow relative to simulated biomass and then caught up with the simulation in March and then slowed considerably after about 35 t ha\(^{-1}\) biomass had been produced. Measured biomass accumulation in the 9d crop was as rapid as could be expected from the APSIM-Sugarcane simulations until February and then growth rate slowed down when about 40 t ha\(^{-1}\) biomass had accumulated. Biomass measured in the 11d crop was similar to simulated biomass for 8 of the 11 samplings and lower in the remaining 3 samplings (Figure 3). Measured growth of this crop slowed down when it had produced about 50 t ha\(^{-1}\) biomass and this corresponded with a reduction in simulated growth due to simulated lodging. Although lodging was not measured it was noted that extensive lodging occurred after heavy rains in April 2006 (Figure 1). The cane yield for this crop was well above the industry average (112 t ha\(^{-1}\)) for 2004 and 2005 (Webb, 2006) but yields for the other crops were less than the industry average (Table 1). The sucrose content for 9a was high and compensated to some extent for the low cane yield.
Table 1. Yield and sucrose content of experimental crops measured at the final sampling of each crop.

<table>
<thead>
<tr>
<th>Date</th>
<th>Experiment</th>
<th>Biomass (t ha⁻¹)</th>
<th>Cane yield (t ha⁻¹)</th>
<th>Sucr. Cont. (%)</th>
<th>Sucr. yield (t ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25/07/2006</td>
<td>11d05</td>
<td>64.5 ±2.3</td>
<td>158±4.7</td>
<td>14.5±0.5</td>
<td>22.9±1.3</td>
</tr>
<tr>
<td>28/06/2004</td>
<td>9a03</td>
<td>38.6±2.8</td>
<td>85±7.0</td>
<td>18.1±0.1</td>
<td>15.4±1.3</td>
</tr>
<tr>
<td>5/04/2005</td>
<td>9d04</td>
<td>44.4±2.3</td>
<td>105±4.8</td>
<td>16.2±0.2</td>
<td>17.1±0.9</td>
</tr>
</tbody>
</table>

**KC prior to canopy closure**

Only 11d had sufficient valid data for an analysis of KC from the early stages of canopy development to 80% canopy closure. KC was about 0.25 shortly after the BREB system was installed and canopy cover was about 10% (Figure 4). KC rose to 1.4 after the next irrigation and to similarly high values after the next three irrigations (Fig). KC decreased as the soil surface dried and it increased gradually as the canopy continued to develop. An equation

\[ KC = 1.08 - \exp(-3212I) + 0.653\Phi^3 \]  

including terms for relative soil water content (\(\Phi\)) near the surface and fractional light interception (\(I\)) was fitted to KC data in Figure 4 (NONLIN procedure SYSTAT) and accounted for 74 % of the variation in measured KC. Thus the equation incorporates vegetation and soil components of the ‘dual KC approach’ of Allen et al. (1998). KC increased with canopy development at a diminishing rate and it increased with soil water content near the surface at an increasing rate. The very high KC values after irrigation were likely to result from the presence of flowing or ponded water in the irrigation furrows for periods of up to 24 hours.

**KC 5d means after canopy closure**

KC was influenced significantly by relative soil water content after canopy closure (>80% radiation interception) in all experiments (p=0.005, 0.013 and 0.047 for experiments 9a, 9d and 11d). Relative soil water contents between 0.5 and 1.0 had no significant effect on KC in any experiment (p=0.419, 0.769 and 0.614 for experiments 9a, 9d and 11d) and BREB data for only the wetter range of soil conditions were included for the following analysis of climate and crop effects on KC.

Valid 5-day KC means were obtained throughout the calendar year only for the 9a crop (Figure 5). Only 5 valid means were obtained for the 9d crop and these were in the wet season (Dec to March) whereas valid KC values for the 11d crop were in the dry periods September to November and April to June (Figure 5). KC was mostly
less than 1.0 for the 9a and 9d crops. After the wet season KC was 0.4 to 1.1 for the 9d crop was mostly greater than 1.0 for the 11d crop. Prior to the wet season KC was between 0.6 and 1.3 for the 9d and 11d crops. The high KC values in September for 11d occurred when ET0 was also at peak values for the season and mean 5-day ETC was about 8 mm d⁻¹. The difference in KC after the wet season between 9a (low) and 11d(high) is interesting because neither crop was growing much at the time but 11d had reached nearly twice the biomass of 9a. The regression of KC means on total biomass was significant (p=0.05, Y=0.81+ 0.0043X (X in t ha⁻¹)) when data from all experiments was pooled but not for individual experiments. The regression on biomass gain between samplings was not significant. There appears to be no reason other than the size of the crop to explain the large difference in KC between 9a and 11d after the wet season. High KC values for 11d in September may be due to the influence of soil evaporation in a canopy that was not quite complete (Figure 2).
Scheduling experiment

The four treatments were irrigated three times simultaneously during canopy development and 11, 13, 14 and 17 times thereafter for the Low, Medium, Variable and High treatments respectively (Figure 6). Irrigation amount was not known and it was clear from the soil moisture measurements that the profile was not always refilled completely after each irrigation (Figure 6).
The mill broke down during the harvest operation resulting in a failure to capture juice samples from two replications of the High treatment and one sample from the Medium treatment. The mean sucrose % cane for all samples was 13.5 % and mean sucrose yield was 17 t ha⁻¹ which is a high yield for Ord ratoons. Cane yield was reduced significantly when less than 17 total irrigations were applied in the Variable and Low treatments, both using a mid-season $K_c=0.75$ at some stage (Table 2). The yield difference between the Medium and Variable treatment was 5 t ha⁻¹, with only one less irrigation. In March and April, water deficits in the Variable treatment were large compared to the Medium and High treatments (Figure 6) and these large deficits probably resulted in the yield loss. The three additional irrigations required by increasing KC from 1.0 to 1.25 did not increase yield significantly (Table 2).

Table 2. Mean cane yield for four irrigation treatments of the scheduling experiment.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Total Irrigations</th>
<th>$K_c$</th>
<th>Cane Yield (t ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>14</td>
<td>0.75</td>
<td>121</td>
</tr>
<tr>
<td>Variable</td>
<td>16</td>
<td>1.00/0.75</td>
<td>126</td>
</tr>
<tr>
<td>Medium</td>
<td>17</td>
<td>1.00</td>
<td>131</td>
</tr>
<tr>
<td>High</td>
<td>20</td>
<td>1.25</td>
<td>133</td>
</tr>
<tr>
<td>LSD (p=0.05)</td>
<td></td>
<td></td>
<td>4.3</td>
</tr>
</tbody>
</table>
4. Discussion

The three ratoon crops produced markedly different biomass yields depending on the ratoon date and ratoon age. Because the crops were grown in different years they needed to be compared through the APSIM-Sugarcane benchmark. The model integrated temperature, rainfall, irrigation and radiation inputs as best as currently possible to show that all crops accumulated biomass nearly as well as could be expected at least up to a point. Biomass accumulation in the 9a crop practically stopped when it had produced about 30 t ha⁻¹ biomass even though it was still erect and should have kept growing according to the APSIM simulation. The 9d crop grew less than expected when 40 t ha⁻¹ biomass had accumulated. The 11d crop slowed down when about 55 t ha⁻¹ biomass was reached but this was to be expected particularly after the large storm in March which exacerbated lodging. KC for the August and September ratoons seldom exceeded 1.0 whereas KC for the 11d crop often exceeded 1.0 with a overall mean value of 1.09 compared to 0.89 for 9a and 0.92 for 9d. Thus KC increased with crop yield which is to be expected since biomass accumulation and transpiration are normally highly correlated (Tanner and Sinclair, 19xx). However there was no correlation between measured biomass accumulation and KC between sampling dates. The scheduling experiment indicated that using KC= 1.0 was appropriate for achieving near maximum yields and avoiding water wastage. Yield was not improved by increasing KC to 1.25 even though this was a high yielding crop (about 130 t ha⁻¹) compared to the average yield in the Ord for 2005 (111 and 144 tons ha⁻¹ in 2002 and 2003, Mock (2004)). A yield of 130 t ha⁻¹ was not as high as in the 11d BREB experiment in which KC after canopy closure reached 1.25 when the yield was over 150 t ha⁻¹. For very large crops KC may need to be increased to 1.25 which is the KC value established for fully canopied sugarcane in Queensland and Swaziland (IB and McGlinchey, 2003). The increase in KC in large crops could arise both from the increased crop height and lodging which would reduce aerodynamic resistance to transpiration (Monteith and Unsworth, 1990) even if the growth rate is reduced. KC did not decline as expected during the later stages of development in a lodged crop in Queensland possibly for this reason (IB and McGlinchey, 2003).

KC prior to canopy closure depended on canopy cover and soil water content near the surface as may be expected. Both the measurements and modeled KC in Figure 4 resembled the stylized dual crop coefficient curve in Smith (2000) where the contribution from soil evaporation (KE) causes KC to reach 1.4 after rain or irrigation and then KC declines to a base level (KCB) determined by the level of crop cover. From eqn 1 KCB = 0.08 when I = 0.0 and KCB = 1.0 when I = 0.8 or when canopy cover = 80%. This is in agreement with data from Inman-Bamber and McGlinchey (2003) which showed that in terms of crop water use the canopy was essentially complete when it intercepted more than 80% of incident radiant energy. According eqn 1 the effect of soil water content is independent of canopy development and KE reaches 0.6 when relative soil water content = 1.0. This implies than KC can reach about 1.6 when the soil surface is very wet as after an irrigation.

The three BREB experiments indicated that KC for Ord sugarcane is about 1.0 after canopy closure, compared to 1.25 obtained from BREB experiments in the Burdekin region of Australia and in Swaziland (Inman-Bamber and McGlinchey, 2003). This difference raises the question about a maximum ETc for sugarcane regardless of atmospheric evaporative demand. Maximum daily ETc was 7.5 mm d⁻¹ in Ord sugarcane when neutron moderation measurements were made before and after each irrigation (Plunkett and Muchow, 2003). Maximum ETc recorded with BREB equipment in the Burdekin seldom exceeded 8 mm d⁻¹ (Inman-Bamber and McGlinchey, 2003). Maximum ETc of sugarcane measured with a neutron probe in the Burdekin was 7.8 mm d⁻¹ (Ham, 1985). Mean ETc of three sugarcane lysimeters at Pongola in South Africa exceeded 8 mm d⁻¹ on only 4% of days in the nearly 5-year period when readings were taken (Thompson, 1986). It is possible that there is a limit to the amount of water that can be transpired from a full canopy of sugarcane. One possible explanation is the low level of plant-atmosphere coupling that has been found in well irrigated sugarcane (Meinzer and Grantz, 1989). Under such conditions the feed-back between plants and their immediate aerial environment may diminish the dependence of transpiration on stomatal conductance (Steduto and Hsiao, 1998).

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We thank Mr Gerard Morgan and Mr Maurice Darlington for their assistance with managing the trials and David Fanning for designing and building the BREB mast.

References


Figure Captions

Fig 1. Crop coefficient ($K_C$) in BREB experiment 1 in moist (SWC40>0.32, open symbols) and drying soil surface conditions (SWC40<0.32, closed symbols). Fractional interception of solar radiation (FIR) is shown as a line.

Fig 2. Crop coefficient ($K_C$) in BREB experiment 1 in relation to soil water content (SWC40) estimated from reflectometer readings at 40 mm soil depth.

Fig 3. a) Daily rainfall and net irrigation (amount was calculated not measured) b) measured (symbols) and simulated (line) fraction of interception of solar radiation (FIR), c) crop coefficient ($K_C$) for all valid recordings of $ET_C$ obtained from the second BREB experiment (BREB1). Closed symbols indicate possible lack of soil moisture for maximum transpiration. Dotted line is $K_C$ used in $ET_C$ estimation.

Fig 4. Crop coefficient derived from BREB1 measurements and total soil water derived from capacitance sensors. Open symbols are for December and January and closed symbols for April and May.

Fig 5. Range in simulated fractional interception of radiation (FIR, vertical symbols) in relation to cumulative daily heat and radiation (radiation+0.3(mean temperature-7.0)) and best fit to mean for each range (line, $Y=0.876(1.0+\exp(4.02-0.00289X))$). Radiation was in MJ m$^{-2}$ d$^{-1}$.

Fig 6. Daily total soil water (TSW) in top 1 m of soil (solid line) and daily soil water deficit (SWD, broken line) determined from $ET_C$ measured by BREB1 and $ET_C$ estimated from $K_C \times ET_0$ (See Fig 3). The number of valid $ET_C$ measurements is provided for each month.

Fig 7. Daily rainfall (top), nominal net irrigation and total soil water (TSW) in the top 1 m soil determined by capacitance for four treatments (high, medium, variable, low) in the irrigation scheduling experiment.

Fig 8. Cumulative distribution frequency for $ET_C$ (solid lines) and $ET_0$ (broken lines) for the Ord BREB experiment 2 (thick lines) and for the Burdekin experiment (thin lines) of Inman-Bamber and McGlinchey (2003).

The application of climatic data for planning and management of sustainable rainfed and irrigated crop production


Smith, Martin
APPENDIX 9

Why knowing ET is central to crop water needs

This is the first in a series of articles from the CSIRO aimed at keeping informed about productivity issues in the sugarcane industry. The author of this article is CSIRO scientist Geoff Inman-Bamber.

The growing body of knowledge being accumulated by CSIRO sugar researchers includes a detailed understanding of the interaction between energy and water in the sugarcane growing cycle.

CSIRO wants to put this information into the hands of sugarcane growers so that they can put it to use on the farm. It will allow growers to irrigate their crops with minimum water wastage and maximum crop benefit.

In sugarcane crops, the sun’s energy is used mostly for evaporation and heat, with only about 1-2% directly used for crop growth. The crop uses 100 times more water than it retains in the stalks to supply water for evapotranspiration (ET).

ET is simply a combination of evaporation from the soil and transpiration from the leaves of the plant. It is an important measure because it equates to how much water a crop needs.

If soil water is lacking, growth and transpiration slow and the air heats up. Solar radiation, wind, humidity and temperature all affect ET, as well as canopy size and crop height. For example, the taller the crop the more air turbulence develops just above it, and this has implications for water usage.

Using hourly weather data and estimates of canopy development, we can work out how much water is needed every day.

Our research shows that sugarcane seldom uses more than 8 mm a day, simply because there are physical limits set by energy entering and leaving the system.

In the near future, sugar farmers will be able to access this information on the internet, tailored specifically for their crop.

A prototype is under development and being trialled in the Ord River in Western Australia and Bundaberg in Queensland. It should be available in a few years.

The system, called WaterSense, is a simple interactive web page that shows clearly when irrigation for a particular crop should be scheduled.

The system obtains a range of relevant data from an automatic weather station and calculates when each paddock should be irrigated and, combined with specific information growers provide, will give an accurate schedule for irrigation.

For more information contact Dr Inman-Bamber at Geoff.Inman-Bamber@cse.csiro.au.

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APPENDIX 10

Kimberley Echo
01/12/2005
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BY BILL WEBB

At the end of Crush Week 28, 393,400 tonnes had been crushed at an average Pal© rate of 13.93 (12.54 cts).

The mill continues to experience problems. Hopefully the rain will stay away for a bit longer to allow as much as possible of the estimated 54,657 tonnes remaining to be processed.

The irrigation system will be shut down in early December for maintenance before the wet season.

As the mill relies on this system for its water supply, it will also have to shut down at this time and will not restart.

An extensive maintenance and upgrading program at the mill will result in a late June 1 start to the 2006 season.

Replacement of the troublesome STG mills is welcome tangible evidence of commitment to the future of the Ord’s sugar industry.

With the exception of occasional storms, the weather remains hot and dry. Temperatures in the low 40s and relative humidity in the low teens are keeping irrigators busy.

Fully canopied young plant cane is now on a 10-day irrigation cycle. Heat stress and windburn are obvious in many blocks. Despite this, the young crop is looking well and expectations for a good crop, despite a reduced area under cane, are high for the 2006 season.

Irrigation

Ord growers are always on the lookout for novel technology, which may improve irrigation efficiency. One family farming group has recently commissioned a trial ‘level furrow’ irrigation system, which has the potential to achieve increased efficiency.

The system involves levelling a block to zero row fall and zero crossfall, and superimposing furrows on this. Water is applied from a central shallow supply ‘channel’ and finds its way by virtue of water depth alone (zero fall) along each of the furrows.

The system eliminates the need for siphons and eliminates almost all ‘tail water’. Water applied to the block, once the supply is cut off, stays on the block.

The first trial run highlighted some minor modifications, which could improve the system, but in general it worked well on the freshly cultivated land. The ‘unknown’ at this stage is how the system will cope in reverse for drainage once the wet season begins, but there is no reason to assume that getting the water off will be less effective than getting it on. All irrigators in the Valley will be watching the performance of this system over coming months.

General

November has been a busy month for visitors. Early in the month, SYDIV Researchers Alan Garside and Brian Robotham spent a week updating growers on new farming systems which would suit Ord conditions.

Alan and Brian were impressed with the uptake of new farming systems already being trialled by Ord growers.

Mid-month, CSIRO Researcher Geoff Inman-Bamber presented growers with an update on irrigation research and irrigation scheduling technology.

Excellent performance of the sophisticated Bowen Ratio Energy Balance equipment has allowed further fine-tuning of the internet-based irrigation-scheduling program, particularly in the early stages of crop growth.

Growers expressed their desire to continue this work for a further 12 months to confirm the results obtained this season.

Late in the month, SRDC’s Russell Muchow presented growers with an update on SRDC programs and activities.

As this report goes to press, all in the ORIA are looking forward to the beginning of the wet season to provide a break from the current build-up conditions.
Kimberley Echo
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Level narrow irrigation - the potential to achieve increased efficiency.
APPENDIX 11

Australian Canegrower
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Ord growers building irrigation capacity

Start flashing terms like “FAO 56”, “Penman Monteith”, “ET Nought”, and “Kc” around and people may start to wonder.

Not so sugarcane growers in the Ord River, Western Australia. They are becoming quite familiar with the terms, how to use them and what to expect from them.

The state-of-the-art irrigation management terms and the refinement of their application in the Ord are some of the outcomes being achieved by a CSIRO and Western Australian Department of Agriculture research project.

Begun in 2002, the SRDC-funded project is focusing on building the community’s capacity to save water, labour and reducing irrigation’s impact on subsurface water tables.

The irrigation management trials established at the Frank Wise Institute for Tropical Agriculture Research in Kununurra have zeroed in on sugarcane’s water requirements specific to the Ord River’s conditions.

State-of-the-art equipment is being used to monitor crop water requirements on site, while trials using different irrigation frequencies are carried out.

“A Bowen Ratio Energy Balance assembly, located inside a sugarcane crop, constantly monitors energy balance using a number of different sensors,” said CSIRO Project Leader Geoff Inman-Bamber. “These measurements provide an accurate assessment of the crop’s ability to transpire water.”

Daily weather information, including temperature and radiation, is being recorded to calculate the daily amount of evapotranspiration - the total evaporation of water from the soil surface and its transpiration through the plant leaves.

“The crop’s ability to transpire is combined with the daily potential for evapotranspiration to give us the crop’s daily water use,” said Bill Webb the project’s Extension Agronomist.

“We are aiming to match irrigation supply to crop water use at the right time.”

The project also supports an extension component to test research-developed irrigation requirements under commercial conditions with Ord growers.

For further information contact Geoff Inman-Bamber on (07) 4753 8587 or Geoff.Inman-Bamber@csiro.au; or Bill Webb on (08) 9166 4010, 0418 185 242 or BAWebb@agric.wa.gov.au

Above: Bill Webb, of the Western Australia Department of Agriculture, inspects an EnviroSCAN installation (which measures soil water content at various depths). Below: this is the Bowen Ratio Energy Balance installation, used to measure evaporation and transpiration every 20 minutes.
APPENDIX 12

Landline - 21/11/2004: Things looking up for Ord River sugar growers. Australian Br... Page 3 of 8

said.

It is all totally irrigated.

"Water is not an issue per se, although you are trying to use a lot more efficiently than you have in the past. Give us an idea of how much less water you are using on this crop than you were even just a few years ago," Peter Lewis asked.

"With sugar cane, I don't know we are using less, perhaps 25 per cent less, and we've found we didn't need to use as much as we have been. Water costs us around $200 per hectare per year. There is a charge per megalitre but it's not all that high. Our main cost is the administration, the maintenance of the channel and that sort of thing, that's 200 bucks per hectare per year," Mr Lech said.

At that price you might have thought they happily sloshing around in the stuff. But the fact is irrigators here are using on average 25 per cent less, in some cases 50 per cent less than they used to, to grow sugar five years ago and they'll be using even less in future thanks to this research project currently underway in the Kununurra canefields.

"Geoff give us a broad outline of this project here," Peter Lewis said.

"Sure Peter. Well the main idea is to find out exactly what the crop needs in terms of water use, so we can better match irrigation to water use and prevent excessive use of water and leakage through the system into the ground water," Dr Inman-Bamber, CSIRO said.

"How does it work?"

"This system is based on resolving the energy balance. Water is evaporated as you would know from using energy, and what these instruments do is they determine the amount of energy coming in from the sun, also coming up from the ground, and it partitions that energy between evaporation and heating the air. So if you were to walk over a grass lawn onto a road, you would notice a rise in the temperature and what's happening there is there's no water on the road obviously, and it just gets hotter. So this instrumentation is very sensitive in picking up those differences. And it's set at a critical height above the canopy of the crop," Dr Inman-Bamber said.

"You've got to make sure we're actually picking up the signal from the crop over a fairly large distance, probably up to 100 metres maybe 200 metres. We don't want to measure just local affects around us here, so the lower arms got to be about one and a half times as high as the crop. And the upper arm about one metre, or one metre and a half above that."

"And how long has the project been going? How much data do you need to really make a good guestimate of what's going on in the field?" Peter Lewis asked.

"Well we've had this the second year we've had the bone ratio, it's called a bone ratio in an energy balance system. We had it in the ground for two years, we got a lot of data out of it. And we can draw some conclusions about that. We want to try it out in different cropping cycles, and a few other surfaces such as old returns and trashed returns and so on," Dr Inman-Bamber said.

"And the beauty of these widgets is that you can actually sit at your desk in Townsville and monitor it," Peter Lewis said.

"Yeah, at the top there, there's an aerial, and we have a computer in Townsville that downloads the instrumentation every day, about nine o'clock. And I check it once a week or so. And we can fix up we can read download programs, we can do, probably more than you can do actually sitting here, from Townsville.

This is just one of the local projects being funded by the Sugar Research

http://www.abc.net.au/landline/content/2004/s1245779.htm

16/05/2007

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