

**Irrigation Risk Management Strategies to Reduce
Water Use and Maximize Profitability:
A Paradigm Shift in Performance to
\$ Per Unit of Water**

FINAL REPORT

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Project Reference N^o: **CTA038**

Research Organisation: CSIRO Sustainable Ecosystems

Principal Investigator: **Dr N.G. Inman-Bamber, MSc. (Agric.), PhD**
CSIRO Sustainable Ecosystems
Davies Laboratory
Townsville Q 4814
E-mail: Geoff.Inman-Bamber@csiro.au
Tel: 61-7-4781 8587
Fax: 61-7-4753 8600

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Organisation: CSIRO Sustainable Ecosystems
Level 3, Queensland Bioscience Precinct
306 Carmody Road
St Lucia Q 4067

Project Supervisor: Dr N.G. Inman-Bamber
Location: Davies Laboratory
Townsville Q 4814
Tel: 61-7-4781 8587
Fax: 61-7-4753 8600
E-mail: Geoff.Inman-Bamber@csiro.au

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1. EXECUTIVE SUMMARY

The Australian sugar industry is predisposed to maximize the benefits of irrigation because of its geographic and climatic location. However mistakes of older irrigation schemes elsewhere in Australia, need to be avoided. Performance criteria such as \$ produced per unit of water used 'which have the long term aim of very closely matching plant water use with water applied, will be the single most important factor ensuring longevity of irrigation areas' (Meyer, 1997). Matching plant water use and irrigation, requires knowledge of climatic demand for water, soil water supply, and crop response to water deficits.

This project aimed to develop accurate estimates of water requirements for sugarcane with the use of state-of-the-art technology capable of monitoring the interaction of the atmosphere and the cropped surface. This interaction has been captured in a mathematical equation known as the Penman-Monteith equation as well as in several sugarcane specific models and equations. The research aimed to test and improve these equations and models so that they can be applied reliably to meet the aim of matching crop water supply and demand.

An additional aim of the project was to determine how yield-building processes are affected when water supply cannot meet demand. Given that the aim of irrigating sugarcane is to improve sucrose yield and CCS it is important that the process of sucrose accumulation is targeted when managing irrigation. A third aim was to develop recommendations on ways to reduce water use with minimum impact on productivity and maximum enhancement of profitability using new knowledge of crop water requirements and crop response to water stress.

Two divergent approaches were adopted for the project to meet the dual but complementary aims of defining water requirements and investigating water stress physiology of sugarcane. The one was based on sophisticated measurements of energy used to evaporate water from the cropped surface. The other approach was based on more conventional field plot designs in order to establish responses of sugarcane to water stress and irrigation scheduling treatments. The APSIM-Sugarcane model was used extensively in this research.

The research provided sound guidelines for irrigation of sugarcane in full irrigation schemes particularly in the Burdekin. An erect stand of sugarcane with a complete canopy and an adequate amount of water will use 25% more water than a well-kept lawn (reference evaporation) as determined by the Penman-Monteith equation. Irrigation applied to meet this demand is the maximum irrigation required for sugarcane. The experiments identified two important conditions under which irrigation could be applied at less than maximum rates with minimum risk to crop yield. The one situation is when the soil has been saturated by rain (as often occurs in the tropics) and a large amount of water can be supplied from the soil rather than directly from irrigation. The other situation is when the crop has lodged after the wet season. Lodging generally reduces growth rate and water use.

The new findings have been captured in a spreadsheet model now being tested by some growers in the Burdekin in order to improve scheduling of irrigation. This simple computer model has already identified some deficiencies in current irrigation practices where irrigation frequency was too high at times and too low at other times. The scheduling software is an improvement on existing recommendations which are aimed at irrigating when stalk elongation is reduced to 50% of potential. The computerized scheduling method deals with a wider range of conditions including all growth stages, variable soil wetness and burnt or trashed surfaces and it can be applied to any irrigation system. This scheduling system has the potential to save water and enhance yields in all full irrigation schemes. The new findings have also been used to alter irrigation scheduling tables in the Ord. Longer irrigation intervals

in Spring and Summer are now recommended and this should further reduce irrigation use in the Ord and reduce the impact of irrigation on rising water tables.

Knowledge of water stress physiology has been thoroughly upgraded in this project. Processes (cell division and elongation) responsible for leaf extension and leaf emergence degrade relatively soon after irrigation is withheld. Leaf and stalk extension rates are thus highly sensitive indicators of crop water status. Irrigation is often recommended when stalk elongation rate is reduced 50% by water stress. However research in this project showed that biomass yield would not be reduced until stalk elongation rate is reduced to 30% of the potential rate. Under conditions of low evaporative demand (winter), stalk elongation can remain at low levels (<30%) for a long time without a loss in sucrose yield.

The project has delivered other simple crop stress criteria than can be used to schedule limited irrigation and to schedule drying off and harvesting operations. For example a loss of 3 to 4 green leaves would indicate the best time to harvest in order to benefit from increased sucrose storage during drying off. In one experiment that benefit amounted to an additional 3.6 t ha⁻¹ of sucrose.

The results have been published in a number of conference and journal papers. The project contributed substantially to the Sugar CRC short course on irrigation and the results have been presented at numerous workshops. The project has contributed to a new extension project in the Ord (CSE007) where the energy balance technique, mastered in this project is now being used. Irrigation use in the Ord has reduced substantially as result of CSR022 and could be reduced further with the new technology developed in this project. There is continued commitment to promote the scheduling technology arising from this project.

The research has and will benefit international scientific knowledge particularly regarding sugarcane evaporation standards as well as sugarcane water stress physiology. The sugar industry now has internationally accepted standards for determining the water requirement for sugarcane and these may be required to defend water use in the sugar industry in future. The work has strengthened links between Australian, South African and Swaziland sugarcane research bodies because of the collaborative nature of the work.

2. BACKGROUND

In a recent review of irrigation experience in Australia, Meyer (1997) states that the 'Australian sugar industry is predisposed to maximize the benefits of irrigation; because of its geographic and climatic location and established research and extension record and sound economic position'. However he warns that mistakes of older irrigation schemes elsewhere in Australia, need to be avoided. Rising water tables and increased salinity could reduce the longevity of irrigated sugarcane in Australia. Regional water tables in the Ord are rising 10 to 98 cm each year, for example (Sherrard *et al.*, 1997). The sugar industry can ill afford the type of problems arising from over irrigation experienced in the Murray-Darling Basin where waterlogging and salinity have cost tens of million dollars in lost production let alone the damage caused to the environment. As we move into the 21st century water management in irrigation schemes will have to consider maximizing profitability and minimizing environmental impact in the light of increased water costs, increasing demands for alternative uses of water and increased pressure to protect soil and water resources.

Performance criteria such as \$ produced per unit of water used 'which have the long term aim of very closely matching plant water use with water applied, will be the single most important factor ensuring longevity of irrigation areas (Meyer, 1997).

Matching plant water use and irrigation, requires knowledge of climatic demand for water (called atmospheric evaporative demand or AED), soil water supply, and crop response to water deficits. A great deal of international research has been directed at these demand, supply and crop stress issues in response to increasing economic and political pressure on water resources world wide. However sugarcane has been practically neglected in this regard apart from comparatively small efforts in Southern Africa and Mauritius.

Estimates of water requirement of the Australian sugar crop although practical are crude by world standards. Research conducted by in South Africa has led to a better understanding of AED based on the Penman-Monteith (PM) equation. This work has also had considerable influence in Swaziland where irrigation research is confirming the savings of irrigation (15 to 20%) that are possible with PM estimates of AED even though PM was developed from lysimeter and climate measurements made in the '70s. Many components of the PM model need revision in the light of new instrumentation and new knowledge of environmental physics. The Mauritius sugar Industry has followed a similar route, basing crop water use estimates on the Penman equation which deals more simply with the crop-atmosphere interface than the PM equation but represents the bio-physics of crop evaporation a lot closer than the Class A pan. No standards were available in Mauritius to test their estimates. This projects aims to apply state-of-the-art technology for estimating crop water use to confirm or modify the PM equation (and other models if necessary) for Australian conditions and to improve models for predicting irrigation requirement and the risks associated with applying less than is required to meet AED.

Although our knowledge of the physiology of the response of sugarcane to water stress advanced considerably during the SRDC project CSC16S, there is yet much to be learned about how various growth processes are affected during the onset of stress. Research in South Africa has shown that elongation and photosynthetic processes respond differently during the onset of water stress and while this difference may result in increased CCS during drying-off in winter, it is not certain how stalk elongation and sucrose yield are related in summer when deficits can develop more rapidly. This project aimed to investigate the differential responses to water stress amongst various growth processes such as stalk elongation and sucrose accumulation. Irrigation criteria, such as the 50% stalk growth criterion, could then be confirmed or modified in the light of these results.

Given that the aim of irrigating sugarcane is to improve sucrose yield and CCS it is important that the process of sucrose accumulation is targeted when managing irrigation. Knowledge of how sucrose accumulates under varying irrigation regimes may lead not only to increased sucrose yield and CCS but reduced water use as well along with off site benefits such as reduced drainage and runoff.

3. OBJECTIVES

- 3.1. To conduct strategic research to better quantify crop water requirements and soil water supply to allow assessment of opportunities for saving water and improving crop water use efficiency and hence conserving the environment in full irrigation schemes.
- 3.2. To develop the capability for using models to assess the risks and benefits of different water management strategies including withholding water early and late in the growth cycle to save water and enhance CCS (drying off).
- 3.3. To use previous and new knowledge of crop water requirements and the developed risk assessment capability (objectives 1 and 2) to develop recommendations on ways to reduce water use with minimum impact on productivity and maximum enhancement of profitability.

Objective 3.1 was achieved fully.

Objective 3.2 was met in the form of the scheduling model now being tested and applied in the Burdekin. The water balance of the APSIM-Sugarcane model has been improved from the results of this project but more work is required to get APSIM to simulate some of the crop water stress responses properly.

Objective 3.3 has been achieved largely through the combined use of APSIM and the Penman-Monteith model in the Ord (Appendix 8) and through the water production functions generated with APSIM (Appendix 9).

4. RESEARCH METHODOLOGY

Two divergent approaches were adopted for the project to meet the dual but complementary aims of defining water requirements and investigating water stress physiology of sugarcane. The first was a micro-meteorological approach based on partitioning available energy between latent heat and sensible heat. Latent heat is the energy used to evaporate water from the cropped surface and sensible heat is energy used to heat the air above the crop. The ratio of sensible to latent heat flux is known as the Bowen ratio identified by I.S. Bowen in 1926 (Bowen, 1926).

The other approach was based on more conventional field plot designs in order to establish responses of sugarcane to water stress. The methods have been fully described in a series of published and draft papers (Appendices 1, 2, 3 and 7). These methods will be summarized for the two approaches. Field plot experimentation was also used to test the results from the Bowen ratio research.

4.1 Micrometeorology methods

These methods were based on the Bowen ratio energy balance (BREB) as well the combined energy balance and aerodynamic approach for estimating crop evapotranspiration (ET_C) as captured in the well-known Penman-Monteith (PM) equation. Measuring ET_C with the BREB technique requires expensive equipment and a high degree of technical competence whereas estimating ET_C with the PM equation requires only hourly climate variables which are measured routinely in many sites in the sugar industry. Crop factors are required to convert PM estimates of reference evapotranspiration (ET_0) to crop ET_C . Three years of careful experimentation were required to obtain these crop factors. However once these are known, ET_C from a sugarcane crop can be estimated accurately under a wide range of conditions using the PM equation. The scientific methods involved in BREB measurements and PM estimates were described in three papers (Appendices 1, 2 and 3). A brief summary of the methodology follows.

4.1.1 *Experiment 1: Bowen ratio, Millaroo, 1998*

State of the art BREB equipment was purchased by CSIRO in 1998 and was installed in a trickle irrigated block on the farm of Mr John Sexton in the Millaroo region of the Burdekin. The aim of this experiment was to develop capacity to measure ET_C accurately with BREB equipment and to provide evidence that the BREB technique was reliable (Appendix 1). Soil moisture sensors were inserted at various intervals to a depth of 750 mm. Trickle irrigation (I) and rainfall (R) were measured accurately. ET_C was measured each day with BREB system. Irrigation was applied so that drainage (D) was minimal. Runoff (RO) and soil water content (S) were not measured but the uncalibrated soil moisture sensors were able to show changes in soil water content and when these changes (ΔS) were minimal.

The water balance in these terms can be expressed as:

$$R + I - ET_C - D - RO - \Delta S = 0 \quad (1)$$

Only 53 mm rain fell during the experiment so runoff was likely to be small. At times when there was no net change in soil water content ($\Delta S = 0$) the water balance could be simplified to

$$\Sigma(R+I) \approx \Sigma(ET_C) \quad (2)$$

Thus cumulative rainfall plus irrigation should equal cumulative ET_C if the BREB system was working properly.

4.1.2 *Experiment 2 and 3: Bowen ratio, Kalamia, 1999 to 2001*

The aims of these experiments were to determine crop factors for sugarcane and to measure transpiration use efficiency (TUE). TUE a fundamental component of water use efficiency (WUE) and is required for many applications where WUE is an issue. Improved WUE is becoming as much of an issue as improved productivity in many irrigated production systems. TUE is also an important component of the APSIM Sugarcane model.

These experiments were carried out on a block of Q127 dual row in the Burdekin Delta managed by Mr Jeff Cornford. The BREB system was installed soon after Jeff had completed field operations in September 1999. We attempted to capture data for as much of the crop growth period as possible. Crop growth was measured by taking destructive samples to determine biomass yield and other yield components. Light interception was measured with tube solarimeters and leaf extension rate was measured with auxanometers designed and built by the team. Details of these measurements are given for experiment 3 in Appendix 3. Experiment 2 was largely a failure because of difficulties with the BREB equipment. This was disappointing given that the first experiment was supposed to iron out inevitable problems with the new equipment. Details of the second experiment and a log of the problems are given in Appendix 4. These details are important for new installations and for scientists using this equipment for the first time.

4.2 Eplicated field experiments

4.2.1 *Experiments 4 and 5: Scheduling with crop factors, Kalamia Estate, 2000- 2002*

The aim of these experiments was to test the crop factors established in the Bowen ratio experiments. These scheduling experiments have not been published but a detailed description of the methods is provided in Appendix 5. The idea was to schedule irrigation according to a water balance calculated using different crop factors and to monitor soil water content in order to test the accuracy of these crop factors. If the soil became wetter over several irrigations it would mean that the crop factor was too high and the crop was not using as much water as supposed. Conversely if the soil dried out over several irrigations, that would mean that the crop factor was too low and the crop was using more water than supposed. If the soil water content was about the same prior to each irrigation the crop factor would be correct. A neutron moisture meter was used to monitor water content to a depth of 1.2 m. Reflectometers were also inserted vertically to monitor soil water content at 0 to 300 mm and 300 to 600 mm depth intervals in experiment 4 and at the 600 to 900 mm depth interval in experiment 5 as well.

A range of yield components including cane yield, sucrose yield and CCS were determined on two occasions in experiment 4 and in experiment 5.

4.2.2 Experiments 5 and 6: Water stress physiology, Kalamia Estate, 1999 and 2001

These experiments were designed to test current assumptions about water stress responses in sugarcane. These assumptions are required for crop simulation models such as APSIM-Sugarcane or CANEGRO. This information is essential for applications such as designing and implementing irrigation strategies for the use of limited water. The information is also essential for full irrigation schemes where one is trying to reduce water use and increase sucrose yield. It is well known that CCS can be enhanced by allowing some water stress to develop during drying off. However too much stress will reduce cane yield and possibly sucrose yield as well. Additional objectives of this work were to determine the validity of the 50% stalk elongation criterion for scheduling irrigation which is currently in use in Australia and to investigate dry matter partitioning in sugarcane undergoing water stress. We were interested in establishing some plant based criteria to indicate changes in dry matter partitioning so that the water balance could be managed for greatest water use efficiency and highest sucrose content and sucrose yield.

Details of these experiments have been documented in a paper now being revised for submission to an international publication (Appendix 7).

One experiment was managed so that water stress could be imposed during a period of high evaporative demand on a relatively young crop with a well developed leaf canopy. The other experiment was managed so that stress could be applied on a crop with well developed stalks during a period of low evaporative demand. The number of live and dead stalks per m², green leaf area index (LAI), above-ground biomass and components were determined on six occasions in experiment 5 and eight occasions in experiment 6 following the destructive procedure described by Muchow *et al.* (1993). Non-destructive procedures also were adopted to measure stalk height, green and total leaf number leaf and stalk extension rate in both experiments. Soil water content was determined with a neutron moisture meter calibrated for the experimental site.

5. RESULTS AND DISCUSSION

5.1 Water requirements for sugarcane

5.1.1 *Experiment 1: Bowen ratio, Millaroo, 1998*

The objectives of this experiment were 1) to assess BREB as measure of crop water use in sugar cane by closing the water balance, 2) to validate net radiation estimates for use in PM equations and 3) to compare a sugarcane specific PM method with a commercially available PM method as a possible basis for irrigation scheduling in the sugar industry.

Complete results and discussion for this experiment are provided in Appendix 1 which is a paper presented to the Irrigation Association of Australia congress in Melbourne, May 2000. An error was subsequently found in the Bowen ratio calculations and the corrected data is presented below. The error had minimal impact on the interpretation of the results and no impact on the conclusions of this work.

A soil moisture sensor (reflectometer) at a depth of 750 mm did not detect marked changes in soil water content until the rainy season started in January 1999 (data not shown) indicating that drainage during the experiment was negligible. No runoff was observed during irrigation. Rainfall during the experiment was low (53 mm) and runoff from the well-covered soil surface was probably low. Mean relative soil water contents on 5 November when the reflectometers were inserted, and on 21 December, were similar. Total water input from irrigation and rainfall (225mm) and total crop water use (234mm) between 5 November and 21 December were also similar. Cumulative rain plus irrigation and cumulative water use

were similar whenever the change in soil water content was zero (Fig. 1). Closing the water balance at several stages during a two-month period provided confidence that the BREB technique was a reliable means of determining crop water use in sugarcane.

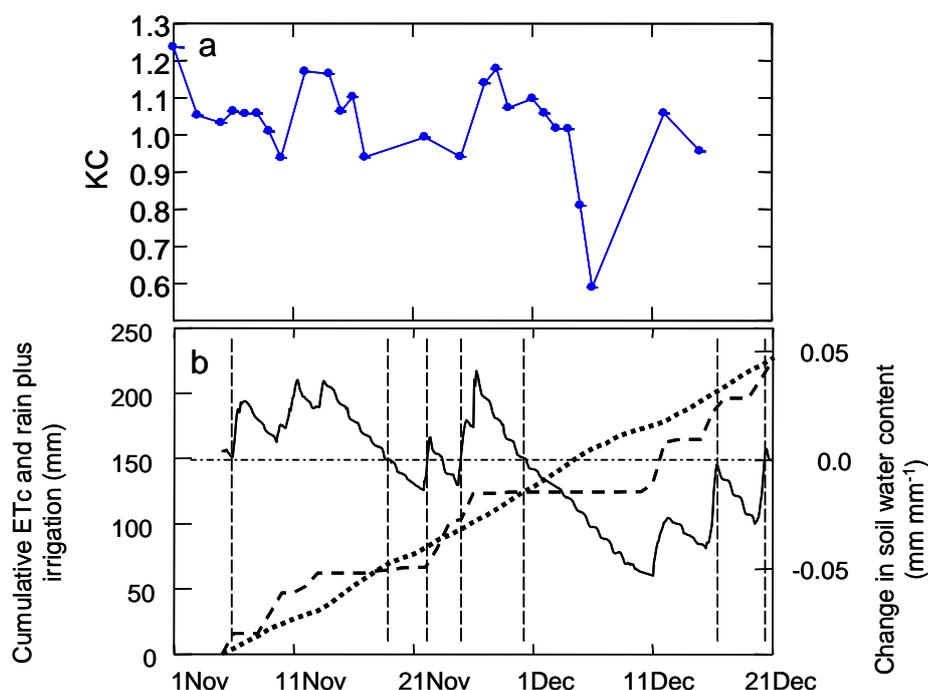


Figure 1. Crop factor ($K_C = ET_C/ET_0$) for days when data acceptance exceeded 70% and net radiation exceeded $5 \text{ MJ m}^{-2} \text{ d}^{-1}$ (a). Cumulative ET_C (dotted line), cumulative rainfall plus irrigation (broken line) and relative soil water content (solid line) for the duration of the experiment at Millaroo.

The crop factor (ET_C/ET_0) at Millaroo was as high as 1.2 when soil water content was high but it fell to as low as 0.6 when the soil was allowed to dry out in mid December (Fig. 1). Further work in well-irrigated crops was required to develop crop factors for sugarcane in various stages of development. By definition, crop factors exclude the effect of water stress on evapotranspiration or crop water use.

5.1.2 Experiment 2: Bowen ratio, Kalamia, 1999/2000

Having established the reliability of the BREB method for measuring ET_C the project now proceeded to use the technique to determine crop factors for sugarcane. This is not to say that these factors had not been estimated for sugarcane before. Crop factors (K_C) for a wide range of crops may be found in a FAO publication (widely known as FAO56) by Allen *et al.* (1998). In this document three factors are provided for all crops, one for the initial stages of development ($K_{C_{init}}$), one for the mid development period ($K_{C_{mid}}$) and one for the end of the crop ($K_{C_{end}}$). Crop factors for transitional phases are then interpolated as shown in Figure 2. For sugarcane these factors in FAO56 are 0.4, 1.25 and 0.7 respectively but there is no indication of how these coefficients were obtained. It is important to verify these factors or to alter them for use in irrigation policy and management in Australia.

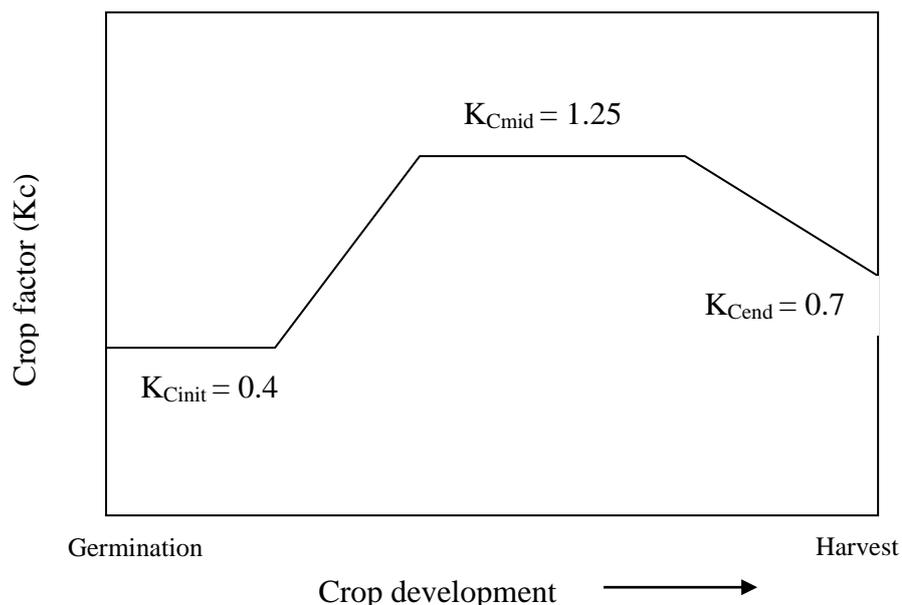


Figure 2. Crop factors for different growth stages of sugarcane as presented in FAO56 (Allen *et al.*, 1998).

Results from experiment 2 in which it was intended to determine K_C during the development of a ratoon crop in the Burdekin delta, were disappointing for the reasons given in Appendix 4. These results have not been published and will be reported here briefly.

Measured ET from the Bowen ratio system (ET_C) and FAO reference evaporation (ET_0) are compared in Figs 3a) and 3b) which show only data that passed strict quality control criteria (Ohmura, 1982) and in Figs 3c) and 3d) which show data where Ohmura's rejection criteria were overlooked but where no other faults could be found. The crop coefficient ($K_C = ET_C / ET_0$) was close to 1.0 regardless of data quality. ET_C and ET_0 were highly correlated and the error of a single estimate (that is ET for one day) was 0.77 and 0.67 mm for high and low data rejection standards respectively. Statistical errors for measured and simulated ET_C based on lysimeter experiments and the CANEGRO model were 0.51 to 0.74 mm per day when 7-day means were used (McGlinchey and Inman-Bamber, 1996). Once we are able to measure ET_C over extended periods we will also be able to consider weekly rather than daily evaporation and this is likely to reduce statistical errors to levels similar to those in the South African lysimeter experiments (McGlinchey and Inman-Bamber, 1996).

From the limited valid data in this experiment it appears that evapotranspiration from sugarcane with a full canopy is about the same as reference ET thus the crop factor (K_{Cmid}) is equal to 1.00

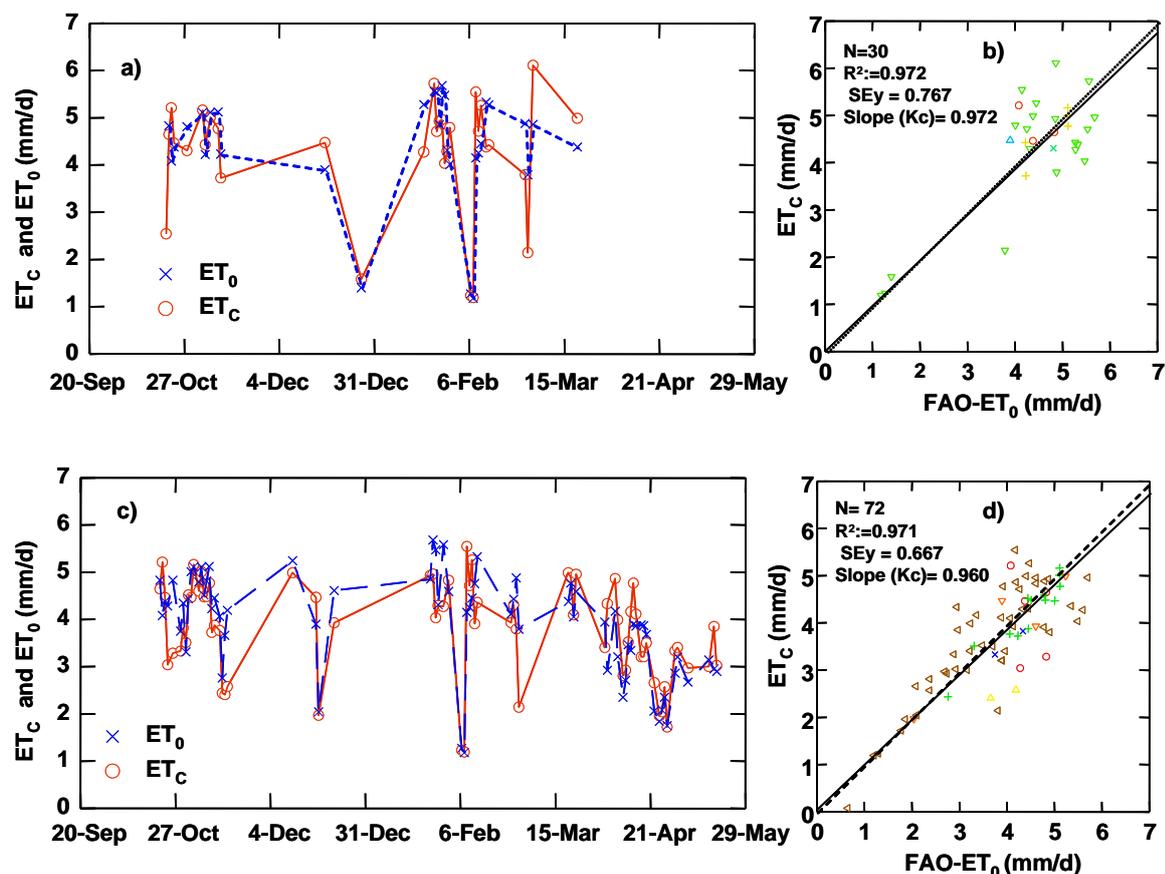


Figure 3. Crop evapotranspiration (ET_C) measured using the BREB (1999/2000) with Ohmura's rejection method in operation and FAO- ET_0 ; time series (a) scatter plot and regression analysis (b). Bowen ratio ET_C without Ohmura's rejection criteria and FAO- ET_0 ; time series (c) scatter plot and regression analysis (d).

5.1.3 Experiment 3: Bowen ratio, Kalamia, 2000/2001

This experiment is fully described in Appendix 3 which is a journal paper based on experiment 3 as well as on field research conducted in Swaziland and South Africa. Unlike experiment 2 valid ET_C measurements were obtained for 193 of the 290 days when the BREB system was operating. Data acceptance rate exceeded 80% for 129 days and it exceeded 90 % for 42 days. The vast improvement in the operation of the BREB was attributed largely to improvements in the airflow connections, external mounting of the mixing chambers and heating of the mirror block from before dawn until dew had evaporated. This last step removed condensation of water in the mirror block before sunrise and prevented further condensation in the very humid conditions after sunrise.

BREB measurements in Australia and Swaziland provided a sound basis for determining the crop coefficient for sugarcane during the middle period of development (K_{Cmid}) as presented in FAO 56 where $K_{Cmid} = 1.25$ (Allen *et al.*, 1998). The earlier estimate of $K_{Cmid} = 1.00$ from experiment 1 was not supported.

ET_C measurements at Kalamia started during the 'development' phase when as little as 5% of incident solar radiation was intercepted by canopy. There was good agreement between measured K_C and K_C determined from FAO 56 while FAO 56 K_C was less than 0.8 (Fig. 4). FAO K_C was calculated following the rules in FAO 56 with $K_{Cinit} = 0.4$ and $K_{Cmid} = 1.25$. Thus $K_{Cinit} = 0.4$ is appropriate. An important finding in this research is that there is no justification for reducing K_C during the final stages of crop development even if lodging

occurs as was the case in the Kalamia experiment. It is possible that K_C would change if flowering occurred however. Growers need to reduce or cease irrigation during this phase (drying off) in order to improve sucrose content (Robertson *et al.*, 1999) but there is no evidence that the demand for water is in fact reduced.

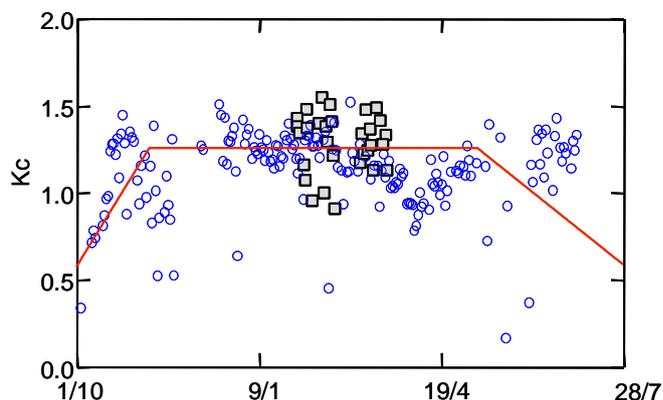


Figure 4. Time course for crop coefficient (K_C) at Kalamia, 2000/01 (O) and Swaziland, 1999 (□), and K_C from FAO 56 (line).

The aim of this experiment was also to establish transpiration use efficiency for sugarcane. The approach to ET estimation in the APSIM model is taken from one of the simpler approaches involving a transpiration use efficiency (TUE) concept proposed by Tanner and Sinclair (1983). Only daily radiation, maximum and minimum temperatures are required for this. The Kalamia experiment provided data to determine TUE of sugarcane for the first time. $TUE = 8.0 \text{ g kPa kg}^{-1}$, originally assumed for sugarcane in APSIM (Keating *et al.*, 1999) was not greatly different from $TUE = 8.7 \text{ g kPa kg}^{-1}$ found in the Kalamia experiment. The range in TUE for maize was 8.2 to 12.0 g kPa kg^{-1} with mean = 9.5 g kPa kg^{-1} (Tanner and Sinclair, 1983), thus sugarcane may be inherently less efficient than maize in the use of water. The new value for TUE gave close agreement between simulated cumulative ET_C and measured cumulative ET_C in lysimeter experiments in South Africa (Appendix 3). There is therefore a sound basis for using APSIM with the new TUE to estimate crop water use on a seasonal basis.

5.1.4 Experiment 4: Scheduling with crop factors, Kalamia Estate, 2000- 2001

In the project plan these replicated experiments were planned to test the crop factors established by the BREB experiments. However when the first crop factor experiment was planned there was no certainty about the value of K_{Cmid} . It seemed at this point that the value was closer to 1.00 than 1.25 as given by FAO56. Experiment 4 was therefore designed to test $K_{Cmid} = 1.00$ and $K_{Cmid} = 1.25$ and to compare both of these with a commercial scheduling system for furrow irrigation.

In this experiment we compared irrigation supplied at $1.25ET_0$ with water supplied at $1.00ET_0$. We compared these treatments with a conventional furrow irrigation treatment which more than refilled the soil profile when a deficit of about 70 mm had developed. This deficit was calculated using $1.25ET_0$.

The irrigation treatments had surprisingly little effect on crop yield components even though as little as 349 mm was applied in the case of the $1.00ET_0$ treatment and rainfall for the duration of the crop was only 793 mm (Appendix 5). If all the rainfall was totally effective, crop water index (CWI) for this treatment would have been 12.3 t cane/ML which is close to the benchmark CWI (Kingston, 1994). However one daily rainfall exceeded 150 mm and it is

unlikely that all the rain could have been used by the crop. A more likely explanation is that the 1.00ET₀ treatment obtained additional water from deep in the soil profile during the period of active growth and frequent irrigation. This conclusion is supported by the reflectometer measurements at 300 to 600 mm in the soil and by NMM measurements below 900 mm (Appendix 5). The crop in all treatments depended on stored soil water during the drying off phase and the fact that yield at harvest could not have been higher judging by the simulation analysis suggests that soil water extraction was rapid enough to meet crop water demand. This demand was considerably reduced after mid-May which is when irrigation ceased.

The data supported the hypothesis that $K_{Cmid} = 1.25$, however scheduling on deeper soils could be based on $K_{Cmid} = 1.00$. This would save a considerable amount of water, expense and labour and would reduce runoff and drainage with associated negative impacts of sediment and N movement off site. The data suggest that conventional irrigation scheduling could lead to considerable wastage of water, needless expenditure and unnecessary offsite impacts.

Lodging was not a factor in this experiment despite the high yields (Appendix 5).

5.1.5 *Experiment 5: Crop factors, Kalamia Estate, 2001- 2002*

The irrigation schedule which was initiated in the first ratoon crop was continued in the second ratoon. Total rainfall for the experimental crop was 705 mm but 320 mm of this fell over two days in mid-February and only 70 mm of this was effective. The crop started to lodge after this storm and it was noted by staff operating the irrigation system that the soil surface was often very wet when attempting to irrigate particularly in the case of the Conventional treatment. Irrigation for this treatment was stopped when water started running off these plots and this resulted in only a small difference in the total amount of irrigation applied to the Conventional and 1.25ET₀ treatments (Appendix 6).

While some crop attributes responded to the irrigation treatments the responses in the most important attributes (cane yield and sucrose yield) were small. Yield differences at harvest between the 1.25ET₀ and Conventional treatments were, if anything, in favour of the 1.25ET₀ treatment (Appendix 6).

After the storm in February there was little difference in soil water content between treatments and there was a general increase in soil water content in all treatments and at all depths down to 750 mm indicating that all irrigation treatments were more than adequate for crop water demand after December 2001. This conflicts with data and conclusions of the previous experiment where the 1.25ET₀ schedule was considered as a good match for crop water required to achieve maximum yield (Appendix 5). It is conceivable that severe lodging after the February storm reduced yield and crop water requirement because of disruption to the leaf canopy.

Simulation analysis confirmed that biomass yields were well below potential when the crop was harvested (Appendix 6). These results bear some resemblance to data obtained in the Ord showing that yield accumulation and water use are substantially reduced after the wet season. In the Ord, irrigation scheduling has been adjusted to match reduced water use at this stage even though an explanation for these reductions has yet to be found. There is mounting evidence in the Burdekin that yield accumulation and water use is markedly reduced after lodging and it is likely that irrigation scheduling can be adjusted to avoid wasting water during this stage.

5.1.6 *Conclusions about water requirements for sugarcane*

Taken together the results from the three Bowen ratio and two scheduling experiments provide some sound guidelines for irrigation of sugarcane in full irrigation schemes and particularly in the Burdekin. There is little doubt that an erect stand of sugarcane with a complete canopy and adequate amount of water will use that water at about $1.25ET_0$ (25% more than reference evaporation). Irrigation applied to meet this demand is the maximum irrigation required for sugarcane. The experiments identified two important conditions under which irrigation could be applied at less than maximum rates with minimum risk to crop yield. The one situation is when the soil has been saturated by rain (as often occurs in the tropics) and there is a large amount of water that can be supplied from the soil rather than directly from irrigation. In this case irrigating at $1.00ET_0$ would allow the crop to obtain up to 20% of its requirement from the soil (indirectly from rainfall). A water budget would need to be kept to ensure that there is always sufficient ‘buffer’ in the soil to avoid depleting all the readily available water. Crop water use for the budget would still be calculated as $1.25ET_0$. Another reason for irrigating at less than $1.25ET_0$ is after the crop has lodged. The evidence for this is somewhat conflicting since the Bowen ratio experiment showed that evapotranspiration (ET_C) could occur at $1.25ET_0$ even after lodging. However during a period in this experiment when growth was poor, ET dropped to $1.00ET_0$ or less but this could not be ascribed to lodging which occurred some time earlier (Appendix 2). Old and new evidence from the Ord (CSR022 and CSE007) and from the project on limited water (CSE001) indicate that yield accumulation when crops are large and/or lodged is often below potential. Water can also be substantially reduced in these conditions. A water production experiment (CSE001) in the Burdekin showed no further yield response to irrigation when more than 500 mm was applied. Lodging was increased markedly by irrigation and it is likely that lodging was responsible for this lack of response.

From this it is safe to assume that irrigation can be applied at $1.00ET_0$ when the crop is lodged and when the soil has been saturated. These conditions occur frequently in the tropics during and after the wet season. Irrigation should be scheduled at $1.25ET_0$ from full canopy up to the point at which lodging occurs and soils are saturated by rain. Crop factors for the period leading up to canopy closure depend on radiation interception by the leaf canopy and by wetness of the soil surface. The APSIM-Sugarcane model can simulate radiation interception by the leaf canopy with good precision (Appendix 3) and it deals logically with evaporation of water from the soil surface. APSIM can therefore be used to generate crop factors for the relatively short time prior to canopy closure as has been done for the Burdekin for a range of conditions (Attard *et al.*, 2003, Appendix 8).

5.2 Water stress physiology, Kalamia Estate, 1999 and 2001

5.2.1 *Experiments 6 and 7: Water stress physiology, Kalamia Estate, 1999*

The results from these experiments (Appendix 7) show that water stress restricts processes (cell division and elongation) responsible for leaf extension and leaf emergence relatively soon after irrigation is withheld. Leaf and stalk extension rate are thus a highly sensitive indicators of crop water status and irrigation criteria based on these extension rates could result in irrigation being applied more frequently than is necessary. The commonly used irrigation criteria for sugarcane in Australia (relative stalk elongation rate (RSER) = 0.5) is safe from the point of view of achieving maximum cane yields but it will lead to greater use of irrigation than is necessary. Under conditions of high evaporative demand (Spring and Summer) irrigating at RSER = 0.3 would not reduce biomass but may lead to some desiccation of leaves and stalks. This desiccation would probably be noticed by growers who would naturally conclude that irrigation was inadequate. However with good experimental

evidence they could be convinced to tolerate this transient appearance of water stress in the interests of saving water, time and money. Under conditions of low evaporative demand RSER can remain at low levels (<0.3) for a long time without a loss in sucrose yield. Cane yield may be reduced under these conditions however and this is desirable if sucrose yield is not reduced.

If water is limiting it is suggested irrigation is applied when leaf senescence begins as a result of water stress. Counting green leaves on 10 adjacent stalks is a practical way of applying irrigation only when necessary to prevent loss of biomass yield. While some desiccation may occur before this stage, sucrose yield will not be reduced under this degree of stress.

In winter the start of the leaf senescence phase in the dry-down process may still be too early to apply irrigation. Data from these experiments suggest that a loss of 3 to 4 leaves would indicate the best time to harvest in order to benefit from increased sucrose storage during drying off. In experiment 7 that benefit amounted to an additional 3.6 t ha^{-1} sucrose. The additional sucrose came at the expense of reduced dry matter in cane tops and reduced cane fibre but not from reduced impurities (mainly hexoses) in cane juice.

The conditions under which this substantial increase in sucrose yield was obtained by withholding irrigation (drying-off) for a period of four months need to be recognized. The soil had a high water holding capacity ($>230 \text{ mm}$). The profile was full after 1482 mm rain fell between 18 December and 28 April. The challenge now is for simulation models to simulate this large response to drying off. Experiments 6 and 7 produced a number of further challenges to current assumptions in the APSIM-Sugarcane and CANEGRO models. When these challenges have been addressed the models can then be used to guide growers on when to stop irrigating and when to harvest to reap benefits possibly as large as those found in experiment 7. Our current drying off recommendations could be substantially improved in this way.

5.3 Economics of irrigation

In the background to this project it was stated that “Performance criteria such as \$ produced per unit of water used 'which have the long term aim of very closely matching plant water use with water applied, will be the single most important factor ensuring longevity of irrigation areas' (Meyer, 1997).” One of the major outputs from research in this project was the capability to estimate crop water use from climatic variables and knowledge of crop growth and development (Appendices 3 and 7). With this capability it is possible to develop irrigation strategies to match crop water demand precisely. Some of these possibilities are now being realized in the form of practical irrigation scheduling tools (Appendix 8). While matching irrigation supply to crop water demand will lead to maximum yield at the same time as saving water from excess irrigation, we have yet to move to the position where water use is based on a balance between social, economic and environmental requirements of both water providers and water users. To this end an economic framework for assessing the economic optimum use of water was established for a range of conditions with varying climatic, soil and management factors. This framework was based on simulations with APSIM-Sugarcane using the new transpiration use efficiency coefficient established from the Bowen Ratio Energy Balance research described in Appendix 3. The concepts of the framework have been submitted for publication to the Australian Journal of Agriculture and Resource Economics (Appendix 9). It is the concepts presented in this paper that are important rather than the absolute values mentioned in the several examples.

The framework of water production functions permits the comparison of the value of water between different regions, soil types, cropping cycles and rainfall categories. ‘In dry years,

for example, an increase in water allocation from 400 to 500 mm/ha, is worth almost twice as much in Maryborough as it is in Mackay'. The concept presented in this paper provides the basis for debate about allocation of water in different regions. Examples are given which include the Burdekin and Tablelands. However the framework can be applied to any region. Its value lies in the large number of factors that can be considered and this will be useful in developing water allocation policies in catchments and irrigation strategies on farm. There is no one simple optimum policy or strategy for any catchment or farm. Rather we need to the tools to assess economic performance criteria and water saving strategies and the framework in Appendix 9 forms the basis for such a tool.

6. OUTPUTS

Two alternative scheduling techniques based at least partly on research in CTA038 were developed in conjunction with growers in the Ord and in the Burdekin (Appendix 8). The first method relies on simple tables while the second uses a computerised system. Both techniques are based on ET_C , knowledge of crop response to water stress and soil water holding capacity (PAWC). The techniques are fully described in Appendix 8. A third simple scheduling technique is suggested for situations where water is limiting.

6.1 Scheduling tables

For the Ord, simulations with the APSIM-Sugarcane model were modified by the Penman-Monteith technique to generate best-bet (median) irrigation intervals for three different crop start dates and three soil types (Table 1) as requested by Ord growers.

Table 1. Best-bet irrigation interval (days) for N Ivanhoe soil using a target soil water deficit of PAWC*50%.

Harvest Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 Jun	11	13	13	14	DD	40-60		14	11	10	10	10
1 Aug	10	13	13	15	17	21	DD	40-60		10	10	10
1 Oct	10	11	13	13	16	20	21	17	DD	40-60		10

DD = dry down prior to harvest

6.2 Water balance scheduling

For the Burdekin, the upgraded APSIM-Sugarcane model was used to determine daily evapotranspiration for crops planted or ratooned in each month of the year. Daily crop water use was divided by ET_0 to determine K_C for each stage of development for each crop. K_C was not allowed to exceed 1.25. Crop factors were determined for conditions when the soil surface was dry or wet and trashed or burnt.

An extract of the spreadsheet containing the water balance model developed for two blocks managed by one grower is shown in Table 2. Information such as block, variety, crop class and crop start date, identifies the field being scheduled. Two other properties, PAWC and target deficit (RAW) were derived from measurements in a similar soil type differing only in the depth of the A horizon.

Table 2. Extract from grower A's water balance spreadsheet.

			Block 14-1				Block 15-1				
			Variety	Q127	Variety	Q117				Variety	Q117
			Class	Plant	Class	3R				Class	3R
			PAWC	120 mm	PAWC	120 mm				PAWC	120 mm
			Target deficit	60 mm	Target deficit	60 mm				Target deficit	60 mm
			Start date	2/04/02	Start date	16/06/02				Start date	16/06/02
Date	ET ₀ (mm)	Rain (mm)	Irrigation (mm)	ETc (mm)	RAW deficit (mm)	Sd (mm)	Irrigation (mm)	ETc (mm)	RAW deficit (mm)	Sd (mm)	
1/09/2002	3.6	0	100	4.5	0	0	100	3.9	0	0	
2/09/2002	3.5	0		4.4	4.4	4.4		2.1	2.1	2.1	
3/09/2002	3.1	0		3.9	8.3	8.3		1.6	3.7	3.7	
4/09/2002	3.5	0		4.4	12.6	12.6		2.1	5.8	5.8	
5/09/2002	3.8	0		4.8	17.4	17.4		2.3	8.1	8.1	
6/09/2002	3.5	0		4.3	21.7	21.7		2.1	10.1	10.1	
7/09/2002	2.3	0		2.9	24.6	24.6		1.4	11.5	11.5	

Unlike the minipan scheduling technique currently advocated for the Burdekin, the water balance technique allows irrigators to have an up-to-date soil water balance or deficit recalculated on a daily basis for the entire crop cycle from germination through to harvest. Irrigation or rainfall amounts that only partially fill the profile are easily accommodated within the water balance model. Thus irrigators applying irrigation via furrow, trickle, high pressure or low-pressure systems would all be able to use the water balance technique. The water balance model offers an advantage over the minipan method, which was designed for furrow systems where PAWC is assumed to fill to capacity after each irrigation.

6.3 Scheduling according to green leaf numbers

A third simple scheduling technique could be used if water is limiting. It is suggested irrigation is applied when leaf senescence begins as a result of water stress. Counting green leaves on 10 adjacent stalks is a practical way of applying irrigation only when necessary to prevent loss of biomass yield. Irrigation should be applied as soon as a steady green leaf count starts to decline. While some desiccation may occur before this stage, sucrose yield will not be reduced under this degree of stress. In winter the start of the leaf senescence phase in the dry-down process may still be too early to apply irrigation. Data from these experiments indicate that a loss of 3 to 4 leaves would indicate the best time to harvest in order to benefit from increased sucrose storage during drying off. These techniques based on green leaf counts require further testing.

7. EXPECTED OUTCOMES

There is continued commitment to promote the scheduling technology arising from this project. CSIRO have a position for a Participatory Action Learning Facilitator based in the Burdekin. Mr Steve Attard is presently in this position exploring opportunities to develop and to promote new irrigation technology and other computationally intensive technologies in the Burdekin and in other regions. We believe this technology has the potential to revolutionize irrigation management in the Burdekin. Steve has visited Swaziland where this type of technology is prevalent and highly successful. The Swaziland example is particularly attractive because it also includes a benchmarking aspect which allows managers to consider paddocks that are not performing to potential. The intention is to develop web-based software

with the help of participating growers, to provide easy access to climate information for up to date scheduling. A new SRDC project (‘Moving from Case Studies to Whole of Industry’) will assist with adoption of technology such as this and will identify the social issues responsible for widespread adoption.

There are considerable challenges to the adoption of new technology in the Burdekin arising from the stability of the production system and longstanding arrangements with existing R&D providers. Nevertheless, community, economic and environmental pressures are likely to encourage changes in traditional methods of irrigation in the not too distant future. Meanwhile it is Steve’s task to develop the scheduling technology with key growers to the point where they can be advocates of the technology and where the technology is readily available to all. At this point there would be a good chance of a paradigm shift in the management of water in the Burdekin and in other schemes. This shift could occur earlier if existing R&D providers picked up this technology and promoted it.

The remarkable result in experiment 7 where an additional 3.6 t sucrose/ha was obtained from drying off also presents a challenge. How can these results be reproduced in commercial cane production? Not only was sucrose yield increased but also the drying off treatment used no irrigation after the wet season. This represents a large saving of water and of labour and money. Some key crop components can be used to modify harvesting schedules to capture this physiological windfall. Steve will be working with select growers to further develop these monitoring techniques.

The research has spin-offs for optimum use of limited water in regions such as Bundaberg. This could be in the form of the simple crop stress indicators (leaf elongation, stalk elongation, green leaf numbers) and in the form of further improvements to the APSIM model which is being used to guide growers on when to use limited water (project CSE001). More accurate simulation of stress responses will lead to better timing of irrigation and better estimates of responses to increased allocation. The latter is a fundamental requirement for optimum use of limited water on the farm and within the catchment.

The research has and will benefit international scientific knowledge particularly regarding sugarcane evaporation standards (as in FAO56) as well as sugarcane water stress physiology. The work has strengthened links between Australian, South African and Swaziland sugarcane research bodies because of the collaborative nature of the work. Experiments 6 and 7 were essentially duplicated in rainout shelter experiments in South Africa and the Bowen ratio work was repeated in Swaziland. More publications will flow from this collaborative work and further collaborative research will be proposed.

8. FURTHER RESEARCH NEEDS

While this project has established crop factors for sugarcane under a wide range of conditions, some conflicting evidence needs to be resolved. The effect of lodging on yield accumulation and water use is complex and extensive efforts in the past to determine lodging effects have produced variable results. Water vapour and CO₂ flux measurements above sugarcane canopies can provide information on crop photosynthesis and evapotranspiration at relatively low variable cost. Our research team now have the equipment and have developed the capability to measure CO₂ flux in addition to capabilities for water vapour flux (ET_C) measurement developed during CTA038. This technology would enable us to fill some of the gaps in knowledge that are evident at the conclusion of CTA038. In addition to the effect of lodging on growth and water use we need to know how water use and hence irrigation requirement is reduced in later ratoons. Knowledge of these effects could further reduce irrigation requirements in the Burdekin, as has been the case in the Ord.

The project produced two new ideas for managing irrigation and drying off based on leaf numbers. Some simple field experimentation is required to test these ideas.

9. RECOMMENDATIONS

Industry needs to take note of the advances in irrigation management in other crops and in sugarcane in other countries. This project has endeavoured to bring some of these advances into the Australian sugar industry and there is a small but determined effort to improve irrigation management using new ideas and technology. Moral and financial support is required to enhance the testing and adoption of these new ideas. The various R&D and E providers need to understand the technology and to support it at least for limited adoption where growers are able to apply it.

10. LIST OF PUBLICATIONS

Journal Papers

1. Inman-Bamber, N.G. and McGlinchey, M.G. (2003). Crop coefficients and water-use estimates for sugarcane based on long-term Bowen ratio energy balance measurements. *Field Crops Research* (in press).
2. Inman-Bamber, N.G. Sugarcane crop yield physiology and soil water deficit. *Field Crop Research* (internal review complete).
3. Stoeckl, N. and Inman-Bamber, N.G. Should Noah have built a dam? Estimating the marginal value of pre-purchased irrigation water with uncertain future rain. *Water Resources Research* (in review, ref. 2003WR002054).

Referred Conference Papers

4. Attard, S.J., Inman-Bamber, N.G. and Engelke, J. (2003). Irrigation scheduling in sugarcane based on atmospheric evaporative demand. *Proceedings of the Australian Society of Sugar Cane Technologists 24*: (in press).
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Popular Articles

12. Attard, S.J. (2002). The impact of different weather conditions on water use. The Burdekin District CANEGROWER, February 2002, p.4.
13. Attard, S.J. (2002). Are the weather conditions boosting potential yields? The Burdekin District CANEGROWER, March 2002, p.4.
14. Attard, S.J. and Inman-Bamber, N.G. (2001). Improving sugar yields through better drying-off. The Burdekin District CANEGROWER, July 2001, p.4.
15. Attard, S.J. and Inman-Bamber, N.G. (2001). Good weather conditions assist 2002 crop. The Burdekin District CANEGROWER, November 2001, p.6.
16. Attard, S.J. and Inman-Bamber, N.G. (2002). How often should I be irrigating? The Burdekin District CANEGROWER, January 2002, p.4.
17. Inman-Bamber, N.G. (2002). How ET boosts profits and crop size. *Australian Canegrower* March 2002 **24**: 21.

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APPENDIX 4.**Extracts from Bowen Ratio diary at Kalamia****30 Aug 1999**

Placed BR gear in field 48 (Jeff Cornford). Mounted arms level at about 1.2 m. Canopy is about 1/3 complete and about 50 cm high. Jeff has just hilled up.

21 Sep

Separated arms, removed fly wire, leveled soil above soil heat flux (SHF) plates, cleaned everything including net radiometer which has mud on top dome.

23 Sep

Spilly replaced mirror with new one, and finalized AWS, still testing soil lysimeters.

29 Sep

Noticed that mirror was not working at about 5.00 pm.

30 Sep 7.00 am

Mirror not working (Tdew=Tref) Recalibrated mirror coarse and fine adjustment. The problem seemed to be that the LED was on all the time regardless of whether mirror was connected or not. Switched pump on and off several times. Eventually LED went off and I was able to calibrate the mirror and get it working. Not sure why?

4 Oct

Noticed that Tdew=Tref for a few days. Asked Spilly to try to fix problem. Spilly went down in afternoon and recalibrated the mirror. However later I noticed that mirror had been working for this day.

7 Oct

Still having problems with mirror going on and off unpredictably. Notified Campbell (Steve). Spilly will put old mirror back in.

8 Nov

Raised arms cleaned mirror and thermocouples (TC), changed filters but broke anemometer cable when raising mast.

11 Nov

I was concerned about -ve BR due to -ve vapour pressure (vp) gradient. Replaced filters and checked everything. Found tape around join to upper intake was wet. Also fixed break in anemometer cable. Air very dry. Leveled net radiometers (Rnets). Put both intakes level and noted Tdew for next 16 mins.

1/12/99

Steve raised the upper arm from 2 to 3 m above lower arm. He found that the intake tube to the upper arm had been severed about 30 cm below the join. Data for day of year (DOY) 238 to 325 looks very suspect (delta vp). So we have had no good data for about 3-weeks now.

7/7/99

Replaced mirror with new-old mirror from Campbell. Not perfectly clean but a lot better than our old mirror. Found pipe broken into lower arm volume bottle. Fixed this.

13/12/99

Steve and Spilly found tube for lower arm severed just below arm with end now deep in canopy. Data for DOY 346 and 347 consistent with this, Replaced lower arm tubing with old tube in esky (not subject to much UV).

14/12/99

Replaced tube for upper arm. No joins at all now. Raised arms. Lower is about 1.2 m above canopy and upper 3.3 m above lower arm.

18/1/00

Net radiometer domes had filled with water during rain over Christmas, This was probably because end cap was mounted upside down with air holes taking in rain

Tube to lower arm had split in many places and had come off bottle in logger box

Fixed old Net radiometer and replaced domes and silica gel for old and new radiometers

Replaced tubing with remaining old tubing. Raised lower arm now 1.5 m above 3 m canopy and upper arm about 3m above lower arm

3 March 2000

First opportunity to enter paddock in about 10 days

Noted that upper arm had slid down to about 1.7 m above lower arm

Crop has partially lodged so I lowered lower arm and put upper back up to about 3 m above lower arm

Wind vane had been -15 deg out but after raising arm it is about + 15 deg out. My guess is that it moved during high winds over last weekend (26 Feb).

14/3/00

I am worried about BR readings. We are getting -ve VP gradients again and it does not make sense. The gradient seems to change with wind direction. It is possible that the top arm is sensing air coming from the lake to the north. I have corrected wind direction for the error in orientation of the wind vane so 0 deg is about due north. I would like the top arm to come down the mast. We may have to try a few positions to find the right height. First we need to be sure that the arms are in the equilibrium layer (mostly influenced by the crop).

16/3/00

Found wind vane had turned eastwards now at about 80 deg instead of north

Connected tube extensions from elbow on upper and lower arms to filters placed 120 mm deep in silica gel. Found upper arm to be leaking. Tdew upper was about 5 deg and for lower was -3 deg. Bypassed bottles for upper arm. Fixed problem immediately. So I bypassed both arms. Readings looked stable enough. Got arms to agree to 0.4 deg. at near zero Tdew. Would be better to take air for both arms through one filter to avoid differences in air intake under high vp gradient conditions in silica gel bottle.

Lower arm about 1.5 m above lodged canopy and upper arm about 3.5 mm above canopy which is 2.5 to 3.0 m high.

30 March

Visit to BR with Bert Tanner.

31 March 00

Note to Russell Muchow

I need to bring you up to date with some progress with CTA038 and CTA018.

Bowen ratio. We have had several problems with this in recent months. Yesterday we had Bert Tanner (CSI) who is specialist on BR, on site at Kalamia. We are dealing with very small vapour pressure gradients because of the high RH conditions so instrument resolution is critical. I have been leak testing the system recently and found it to be leaking. Bert could not do any better than I and he admitted design flaws in the gear. Our leak test is very severe and it may be overkill but we have to be rock solid on these measurements.

A more serious problem is condensation in the tubing. Some times this takes till midday to disappear. We are trying to find a way around this and Bert has been very helpful with suggestions. By and large he is impressed with the standard of our work which is a relief.

All this means that we have some good data on some days but there are many holes in the data during the wet months.

13 April 00

Mike and Steve installed the new volume system to increase time constant of vp readings. Volume now 2.5 l. Bottles have been bypassed for some time now. The new volumes were leak tested with dry air (see readings for today) but both reached about -1 deg dew point indicating a good seal.

23/8/00

Plant crop harvested.

28/9/00

Installed BR in a position giving max fetch in SE and NE directions. Fetch in S is OK but SW is probably 60 m. Shortest fetch is W (25 rows = 45m). Wind is seldom in 200 to 300 deg range. Lower arm 75 cm above ridge and upper arm 1.2 above lower. Crop height is 30 cm and 50 cm max. Ground cover is < 5%. Flux plates are between rows 27 and 28 across the interrow with two end plates in the ridge. Ridge is 80 cm wide and furrow 100 cm. Tested upper lower response to TCs and Tdew and all ended OK. Leak test is still required. All tubing is new to entry to solenoids.

2/10/00

Did leak test. Tdew reached -4 deg in both arms indicating no leakage. Crop has been sprayed with herbicide and green canopy is much reduced, took photos for canopy cover. Put new program in and lost last weeks data. Forgot to correct time.

4/10/00

Steve corrected time and tied arms to prevent rotation in the wind.

6/10/00

Trouble with mirror, Tdew = c19 C for long periods OK and then <0 eg -3.0 deg. -ve values when pump starts in the morning but also later. Net radiometers need checking for level. Also Rnet2 is +ve at night? Could be Fortran programming problem.

16/10/00

Raised arms and leveled net radiometers.

17/10/00

Cleaned thermocouples, changed filters, cleaned mirror. All looks fine.

31/10/00

We have a fine, very humid and hot day in the Burdekin.

I have just come back from B48 and it is very wet underfoot. My boots were picking up large quantities of mud. Access to F48 will be possible using 4wd only and then with some care not to cut up the headlands. I have cleaned the mirror and thermocouples, as well as exchanging the filters.

Flow rates are both at 500cc/min.

4 tube solarimeters have been placed into the northern side of the crop.

Due to the amount of equipment on the mast I have placed the lower arm as close to 1.5x canopy height as possible. This feat required the use of a ladder - so some sections of the crop are getting tall but this is erratic.

I was not able to raise the upper arm. A second person on another ladder is required or the scaffolding will need to be placed closer. Maybe we could adjust this early tomorrow morning before the guests arrive if Mike was to come down early.

F48 irrigation occurred on 17/10 5:45 am set 3 started; 18/10 6:35 set 4 started; 19/10 set 2 started; and 20/10 set 1 started, 22/10 pump turned off 8:00am. The BR is in set 1 and set 4 is the furthest set from the BR.

8/11/00

Started to move scaffolding. Rain prevented completion of task and we had to get out. Upper solarimeter was left out of positions and we could not raise arms.

13/11/00

Solarimeter replaced but still too wet to move scaffolding.

30/11/00

Scaffolding moved and arms raised. Lower arm was level with canopy so past weeks data is suspect. Lower arm now 1.5 to 2 x canopy height and upper arm 1.2 to 1.5 m above lower arm.

5/12/00

Noticed zero difference between upper and lower Tdew since last Thursday am (30/11/00). Discovered solenoid not working. This appears to be due to Table 2 overrun which fails to set port 2 high when flag 2 is high (see 1.1 in CR23x manual). After turning pump on and off the problem was fixed but we decided to increase table 2 scan rate from 10 to 15 s.

I leveled the net radiometers and faced them E over the cane rather than the cut area around the scaffolding. Arms were secured to face SE.

Jeff started irrigating yesterday am. (4/12/00) and it was pretty wet under foot.

6/12/00

We reduced the time delay for the multiplexer and Mike put a counter after the Set Port high (for solenoids) command to keep a record of number of times per 20 minutes that the solenoid is switched.

11/12/00

Found battery power low and BR off, had a lot of trouble today in Field 48, eventually disconnected the heater which was draining current (GIB).

14/12/00

Mike went down to put new program in and raise the arms 50 cm. Battery still low but we have sorted out the table over run problem looking at the display or *B in terminal mode. Counter still not resetting properly.

15-18/12/00

Cloudy rainy weather arms show little difference in VP or temp, BR close to zero.

18/12/00

Everything seems to be working OK, no table overruns or watch dog errors observed.

4/1/01

Water found in net radiometer, don't think it had been there long because silica gel was still dry. Dome was cracked.

5/1/01

Replaced domes in this and the new radiometer and installed both. Raised arms, replaced domes. Cleaned TC and changed filters. Wind direction seems to have changed, must have rotated a bit though I thought it couldn't. (later, could rotate 180 deg which was noted and corrected).

23/1/01

I was worried about -ve vp gradients in the morning, thought there maybe some condensation in the upper arm tubing.

Notes in diary tailed off after this and things ran smoothly.

APPENDIX 5.

Experiment 4.

Irrigation scheduling of sugarcane based on reference evapotranspiration and crop factors. First ratoon crop 2000/2001.

A replicated trial was established to test the validity of crop factors derived from the Bowen ratio energy balance (BREB) work. The BREB work initially indicated that the crop factor for the post canopy period in sugarcane was equal to reference evapotranspiration (thus $K_{Cmid} = 1.0$). However K_{Cmid} reported in FAO56 is 1.25.

In this experiment we compared irrigation supplied at $1.25ET_0$ with water supplied at $1.00ET_0$. We compared these treatments with a conventional furrow irrigation treatment which more than refilled the soil profile when a deficit of about 70 mm had developed. This deficit was calculated using $1.25ET_0$.

The hypothesis was that if $K_{Cmid} = 1.25$ was true then the soil water content of the $1.25ET_0$ treatment should be about the same before each irrigation. If $K_{Cmid} < 1.25$ then the soil would get progressively wetter before each irrigation and if $K_{Cmid} > 1.25$ then the soil would become progressively drier in the $1.25ET_0$ treatment. If $K_{Cmid} = 1.25$ is true then the soil would become progressively drier in the $1.00ET_0$ treatment. If the hypothesis is true then the yield of the $1.25ET_0$ treatment and the conventional irrigation treatment receiving more water should be the same and equal to the potential yield. The yield of the $1.00ET_0$ treatment would be lower than the other treatments unless the crop was able to extract the additional water it required from deep in the soil profile without becoming unduly stressed. The soil moisture measurements would show if this was happening.

Methods

Seed cane of Q96 for the experiment was obtained from Ayr CPPB Hodder plot and was planted on 27 September 1999. The plant crop was managed to Kalamia estate standards using furrow irrigation and was harvested green on 25 September 2000. Fertilizer was applied shortly after harvesting. The experimental site was divided into 12 plots, 4 replications for each treatment. Each plot consisted of nine rows 1.52 m apart and 39 m long. Six rows were irrigated with trickle tape leaving three unirrigated rows between treatments to minimize interference between treatments. All plant and soil measurements were taken from the four inner irrigated rows (net plot). Trickle tape (Amiad Hydrodrip II – 2435) with 1.8 L h^{-1} emitters 500 mm apart, was installed shortly after harvest. The $1.00ET_0$ and $1.25ET_0$ treatments were irrigated with one line of tape positioned next to the stool and the simulated conventional treatment was irrigated with two lines of tape either side of the stool in order to deliver water more rapidly as would be the case with conventional furrow irrigation.

The following water balance was set up using a spreadsheet on a PC.

$$S_i = S_{i-1} + R + I - K_C * ET_0$$

Where S = soil water content on the i th day, R = daily rainfall, I = irrigation, $K_C = 0.3K_{Cmid}$ during the initial stages of canopy development up to 10 December 2000 and $K_C = K_{Cmid}$ thereafter. For the $1.00ET_0$ treatment $K_{Cmid} = 1.00$ and $K_{Cmid} = 1.25$ for the other two treatments. For $1.00ET_0$ and $1.25ET_0$ treatments a deficit of about 60 mm was allowed to develop before applying 30 mm irrigation. This ensured that the profile never full after irrigation and so minimized drainage below the root zone. For the conventional treatment a 70 mm deficit was allowed to develop before applying 70 to 80 mm irrigation. This would ensure minimal water stress on this soil and would be a similar regime to conventional furrow irrigation on surrounding farms on this soil type.

Neutron probe access tubes were inserted to 1.5 m, one in each plot at the base of the ridge supporting the cane stool and 370 mm from the centre of the cane row. Neutron probe measurements were taken before each irrigation. Two reflectometers (CS615 Campbell Scientific) were inserted vertically in each plot of one replication to measure soil water content over a depth of 0 to 300 mm and over a depth of 300 to 600 mm. These were logged every hour.

Results of scheduling trial

Plant sampling results

A total of 793 mm rain was received for the duration of the crop (25 September 2000 to 18 July 2001). The $1.00ET_0$ treatment received a total of 349 mm irrigation, the $1.25ET_0$ treatment received 508 mm and the

conventional treatment received 672 mm irrigation. Control of error variance was good (Cane yield CV=4.7%) in this trial providing the opportunity of a sensitive test of the above hypothesis. When the crop was sampled in April at 6.5 months, cane yield was 11 t/ha lower in the 1.00ET₀ treatment than in the 1.25ET₀ treatment (Table 1). This difference failed to reach significance by a small margin (p=0.066). Higher sucrose and dry matter contents and lower green leaf numbers in the 1.00ET₀ treatment indicated that this treatment was stressed to some extent in April. Sucrose content in the 1.00ET₀ treatment was considerably greater than in the other two treatments largely because of a higher concentration on a dry matter basis. This effect was not significant probably because only two replications were sampled for juice during the first sampling. The increased sucrose content in the 1.00ET₀ treatment indicates that some ripening had occurred as a result of deficit irrigation. This ripening effect resulted in a significant (>1.4 t/ha) increase in sucrose yield at sampling 1 for the 1.00ET₀ treatment.

Analysis of pooled green leaf number for both samplings showed a highly significant response (p=0.01) to irrigation indicating that expansive growth (leaf area) increased with increasing irrigation. However cane and sucrose yields differed little between treatments when the trial was sampled again in July just before harvest. Control of error variance was not as good in the second sampling (CV=9.7%) as in the first sampling. Yield of cane and sucrose differed less in sample 2 than in sample 1. It is remarkable that yield of cane, sucrose and biomass was not affected by irrigation varying from 349 to 672 mm in a dry year.

Table 1. Summary of analysis of variance of results of plant sampling results on 10/04/01 (Sample 1) and 17/07/01 (sample 2). Total rain for duration of crop was 793 mm. DMC = dry matter content, DM= dry mass, SC=sucrose content.

Crop component	Treatment effects						Statistic			
	Sample 1			Sample 2			1	2	1	2
	F100	F125	Furr	F100	F125	Furr	P		CV%	
Irrigation (mm)	223	346	493	349	508	671				
Deal leaf number per stalk	11.4	9.7	9.7	17.9	16.7	18.5	0.567	0.356	15.9	9.3
Green leaf number per stalk	7.6	9.5	10.9	6.0	8.6	8.9	0.069	0.119	6.8	23.2
Total leaf number per stalk	19.0	19.1	20.5	23.9	25.2	27.3	0.545	0.011	6.8	4.2
Total stalk number per m ²	8.3	9.2	8.3	8.4	8.7	8.4	0.031	0.794	4.5	9.5
Dead stalk number per m ²	0.5	0.2	0.4	1.0	0.8	1.0	0.098	0.275	45.7	25.6
Lear area per gram DM (cm ² /g)	38.8	73.6	45.9	83.3	81.2	82.0	0.082	0.748	14.6	4.8
Leaf area index	1.5	3.8	2.3	2.9	3.6	3.6	0.009	0.399	6.2	22.6
DMC of mature stem	0.264	0.237	0.252	0.305	0.319	0.331	0.056	0.301	1.0	6.5
SC of stalks (DM basis)	0.421	0.367	0.361	0.473	0.463	0.444	0.211	0.148	6.3	4.0
SC of stalks (FM basis)	0.111	0.087	0.091	0.145	0.148	0.147	0.089	0.949	5.9	9.5
Purity %	79.5	75.3	75.6	82.5	84.2	85.6	0.311	0.465	2.9	3.9
Brix	17.7	14.5	15.4	22.7	23.0	23.0	0.059	0.948	3.6	7.0
Cane yield (t/ha)	108.7	119.8	117.0	140.6	142.2	137.4	0.066	0.877	4.7	9.4
Cane yield + dead stalks and suckers (t/ha)	111.3	120.5	118.0	145.3	145.0	141.3	0.147	0.900	5.0	9.2
DM of mature stem (g/m ²)	2867	2841	2952	4280	4556	4539	0.509	0.702	4.6	11.3
DM of trash (g/m ²)	488	333	460	875	746	712	0.026	0.464	14.5	23.5
DM of total biomass (g/m ²)	4068	3992	4190	5694	5997	5917	0.503	0.777	5.5	10.4
DM of total biomass minus trash (g/m ²)	3579	3660	3730	4819	5251	5205	0.564	0.510	5.1	10.7
Sucrose yield (g/m ²)	1206	1043	1064	2030	2111	2013	0.012	0.873	5.0	13.5
Fibre yield (g/m ²)	1399	1548	1616	1921	2141	2251	0.012	0.229	4.5	11.5
Fresh cane mass per stalk (g)	1310	1308	1405	1681	1635	1642	0.082	0.840	4.1	6.9
Dry cane mass per stalk (g)	346	310	354	512	524	543	0.009	0.734	4.1	10.6
Dry total biomass per stalk (g)	490	436	503	681	689	708	0.019	0.830	5.2	9.1

Soil water content

Results of soil moisture monitoring with reflectometers supported the hypothesis (Kc=1.25) reasonably well. Water content in the 1.25ET₀ treatment fluctuated in accordance with irrigation and rain but remained in a

relatively narrow band until irrigation was suspended in May to facilitate harvesting (Fig. 1). In the 1.00ET₀ treatment, water content at 0 to 300 mm was also maintained by irrigation but plants continued to deplete water at 300 to 600 mm even while the crop was being irrigated frequently. Water content declined rapidly in all treatments after suspending irrigation (Fig. 1).

Results from the neutron moisture meter (NMM) were not as conclusive as had been expected. Variations in available soil water depth or volume in the soil layers above 900 mm was such that it was difficult to determine general trends upwards or downwards (Figure 2). However in the deeper layers (>900 mm) it was clear that available soil water decreased in the 1.00ET₀ treatment whereas no such trend was discernable in the 1.25ET₀ or Conventional treatments until irrigation ceased in mid May 2001. Subsequent water extraction at all depths was substantial in all treatments. Soil water depth was generally lower in the 1.00ET₀ treatment than the other treatments both before and after the drying off period.

It can be concluded from both the reflectometers and NMM measurements that scheduling with $K_C = 1.00$ did not match crop demand for water and that the difference was made up by additional root water extraction at depths below 900 mm.

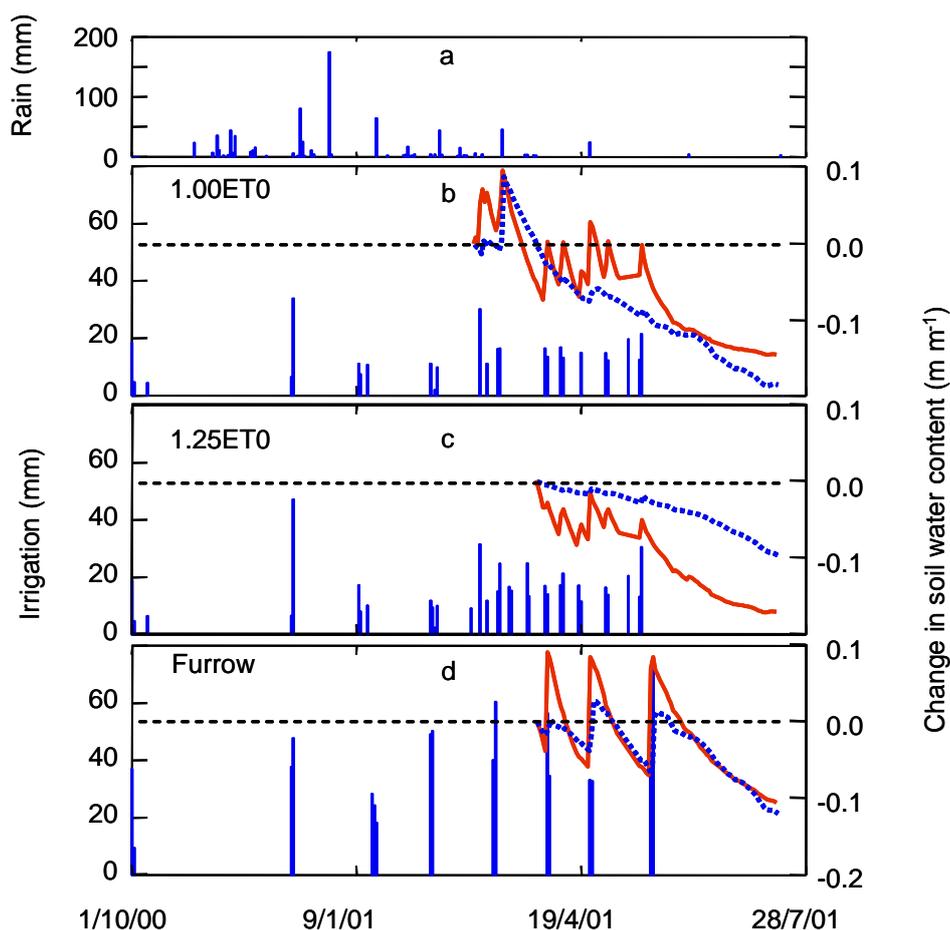


Figure 1. Rainfall (a), irrigation, change in soil water content determined with reflectometry, at 0 to 300 mm (—) and 300 to 600 mm (----) for the 1.00ET₀ (b), 1.25ET₀ (c) and Conventional treatments (d).

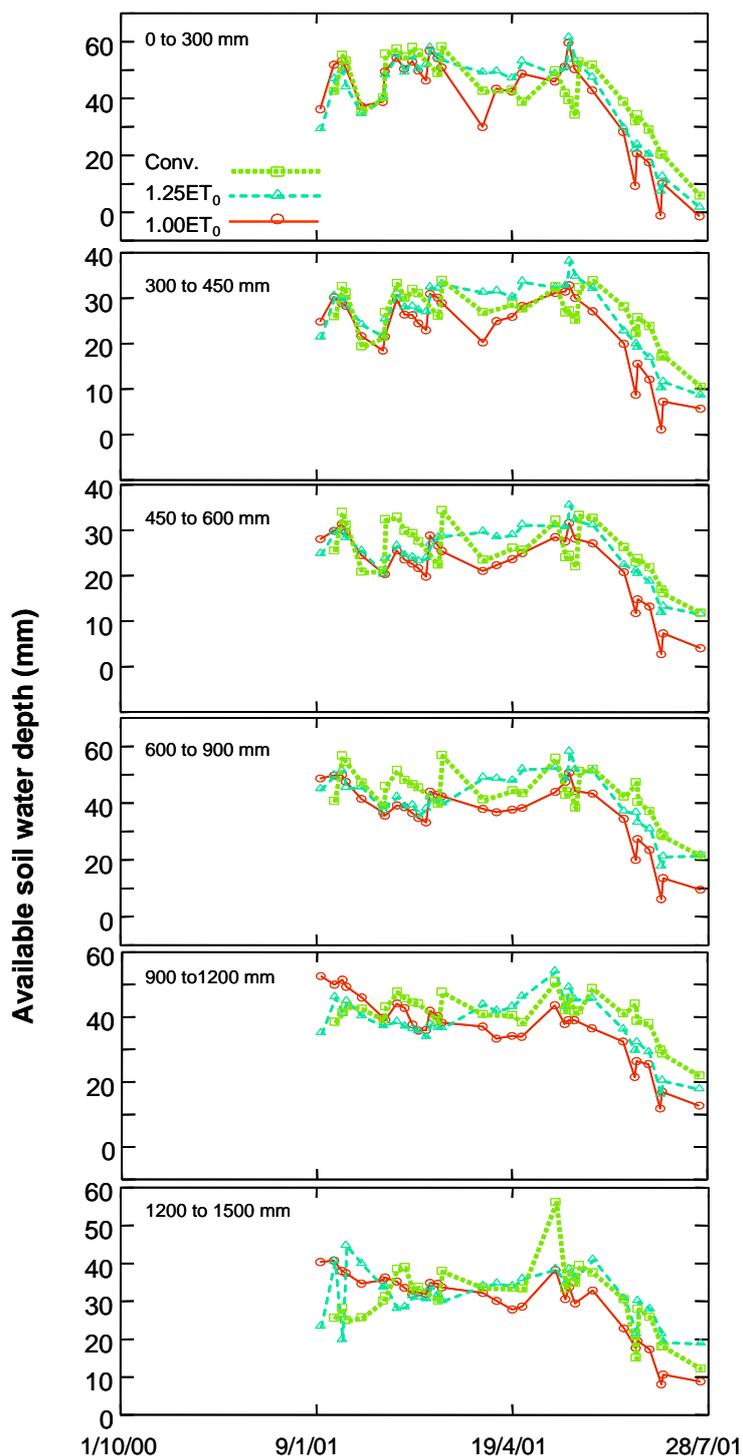


Figure 2. Available soil water depth for successive soil depth intervals and for 1.00ET₀, 1.25ET₀ and Conventional treatments, determined with the neutron moisture meter

Simulation analysis

Hydraulic properties for the soil of the experiment have yet to be analysed. Properties for a Red dermosol (Inman-Bamber et al, 2000) were used as a best guess for this simulation analysis. This ‘normal’ soil profile (1.9 m deep) was used as well as a 2 m extension to this profile (‘deep’ soil) in attempt to explain the yield results of the trial. A fictitious ‘no stress’ treatment was simulated in addition to the three real treatments applied in the experiment. In the ‘no stress’ treatment, water was applied to cancel the soil water deficit when this reached 20 mm.

Cumulative stress days, derived from the photosynthesis stress coefficient in the model, show how the model viewed the development of water stress in the various treatments. According to the model, the 1.00ET₀ was stressed towards the end of the experiment even in the deep soil (Fig. 3). The 1.25ET₀ treatment became stressed in the ‘normal’ soil after irrigation was stopped for drying off. In this treatment water was applied to exactly replace evapotranspiration (ET) using 1.25ET₀ so we would not expect any simulated stress while irrigation was being applied unless there was an error in the application of water or there was some inconsistency between 1.25ET₀ and the model’s calculation of ET using the new TUE coefficient. The minimal amount of stress during irrigation demonstrates that irrigation was just meeting crop water demand and this demonstrates the rigour of irrigation management and the consistency between 1.25ET₀ and the model’s ET estimate.

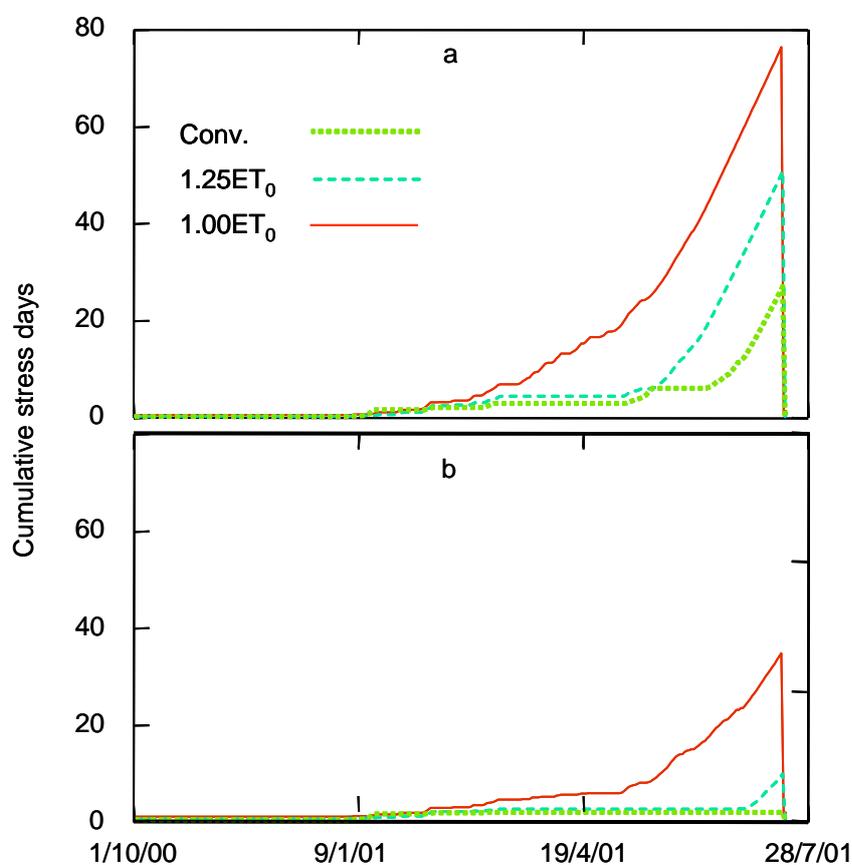


Figure 3. Simulated cumulative stress for ‘normal’ (a) and ‘deep’ (b) soil profiles for the 1.00ET₀, 1.25ET₀ and Conventional

The ‘no stress’ treatment had no stress-days, of course, and the simulated yield in this treatment was close to measured yield in all treatments at both samplings. With ‘normal’ soil depth the model failed to account for the fact that potential yields (yields with no water stress) were obtained in all treatments. With soil depth extended to 3.9 m, simulated yields came close to measured yields in all treatments at sampling 1 and in the Conventional and 1.25ET₀ treatments at sampling 2 (Fig. 4).

It was shown that irrigation after the wet season of 1999/2000 had little impact on sucrose yield at harvest (Appendix 7) suggesting that roots could extract water a great depths to satisfy reduced water demand during winter. Something similar could have occurred here even though the wet season rainfall was quite low. Both NMM and reflectometer data show the extent of water extraction prior to harvesting and yet the crop was not visibly stressed apart from fewer green leaves in the 1.00ET₀ treatment.

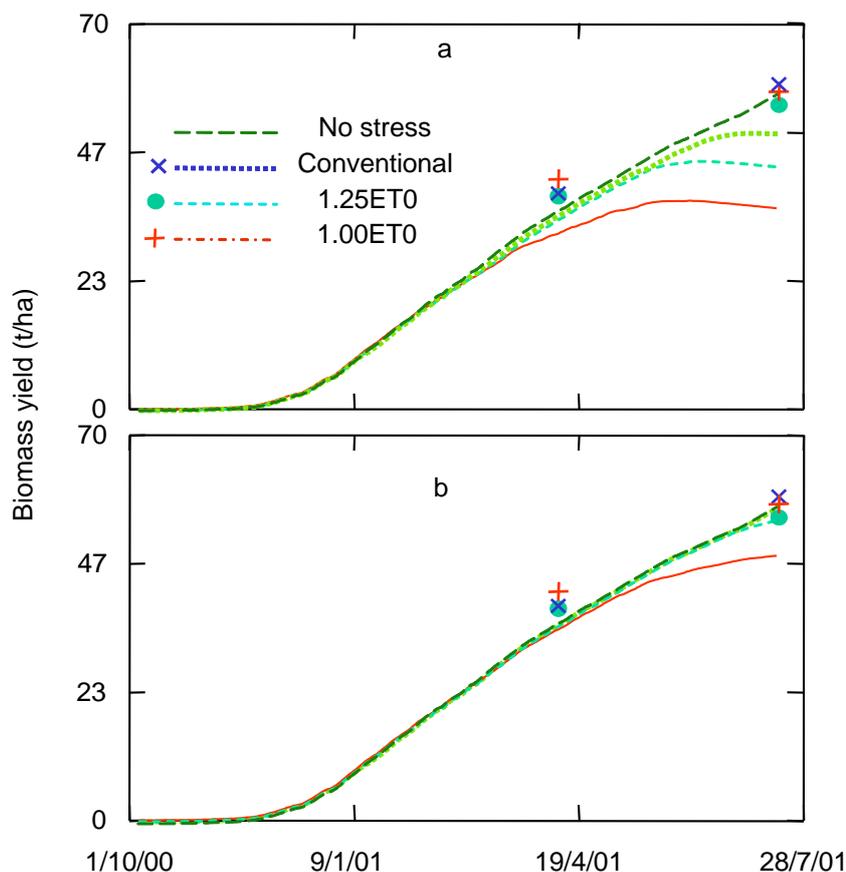


Figure 4. Measured biomass (symbols) and biomass simulated with ‘normal’ (a) and ‘deep’ (b) soil profiles (lines).

Conclusions

The irrigation treatments had surprisingly little effect on crop yield components even though as little as 349 mm was applied in the case of the 1.00ET₀ treatment and rainfall for the duration of the crop was only 793 mm. If all the rainfall was totally effective, crop water index (CWI) for this treatment would have been 12.3 t cane /ML which is close to the benchmark CWI (Kingston, 1994). However one daily rainfall exceeded 150 mm and it is unlikely that all the rain could have been used by the crop. A more likely explanation is that the 1.00ET₀ treatment obtained additional water from deep in the soil profile during the period of active growth and frequent irrigation. This conclusion is supported by the reflectometer measurements at 300 to 600 mm in the soil and by NMM measurements below 900 mm. The crop in all treatments depended on stored soil water during the drying off phase and the fact that yield at harvest could not have been higher judging by the simulation analysis suggests that soil water extraction was rapid enough to meet crop water demand. This demand was considerably reduced after mid – May which is when irrigation ceased.

The data supported the hypothesis that $K_{Cmid} = 1.25$, however scheduling on deeper soils could be based on $K_{Cmid} = 1.00$. This would save a considerable amount of water, expense and labour and would reduce runoff and drainage with associated negative impacts of sediment and N movement off site. The data suggest that conventional irrigation scheduling could lead to considerable wastage of water, needless expenditure and unnecessary offsite impacts.

APPENDIX 6.**Experiment 5.****Irrigation scheduling of sugarcane based on reference evapotranspiration and crop factors. Second ratoon crop 2001/2002.**

The irrigation schedule which was initiated in the first ratoon crop was continued in the second ratoon crop until it was realized that soil water deficit for the 1.00ET₀ and 1.25ET₀ treatments calculated over the full rooting depth was still very large despite regular irrigation to match evaporative demand calculated at 1.00ET₀ or 1.25ET₀. When water is applied to dry soil some of it is held tightly to soil particles and only a portion of the added water is readily available to plants. This phenomenon had been overlooked up to this point (December 2001). A sampling was therefore carried out to assess the crop's response to this practice of scheduling irrigation when the soil is dry. This sampling also allowed us to remove the effect of this practice from future results if necessary. After the sampling we endeavored to raise soil water content in the top 500 mm of soil, to field capacity and then the scheduling treatments were continued. It was noted by staff operating the irrigation system that the soil surface was often very wet when attempting to irrigate particularly in the case of the Conventional treatment after the crop had lodged. Irrigation for this treatment was stopped when water started running off these plots and this resulted in only a small difference in the total amount of irrigation applied to the Conventional and 1.25ET₀ treatments (Figure 1). Total rainfall for the experimental crop was 705 mm but 320 mm of this fell over two days in mid-February. Simulated runoff from this storm was 249 mm so the effective rainfall for this crop is likely to have been only 400 to 450 mm.

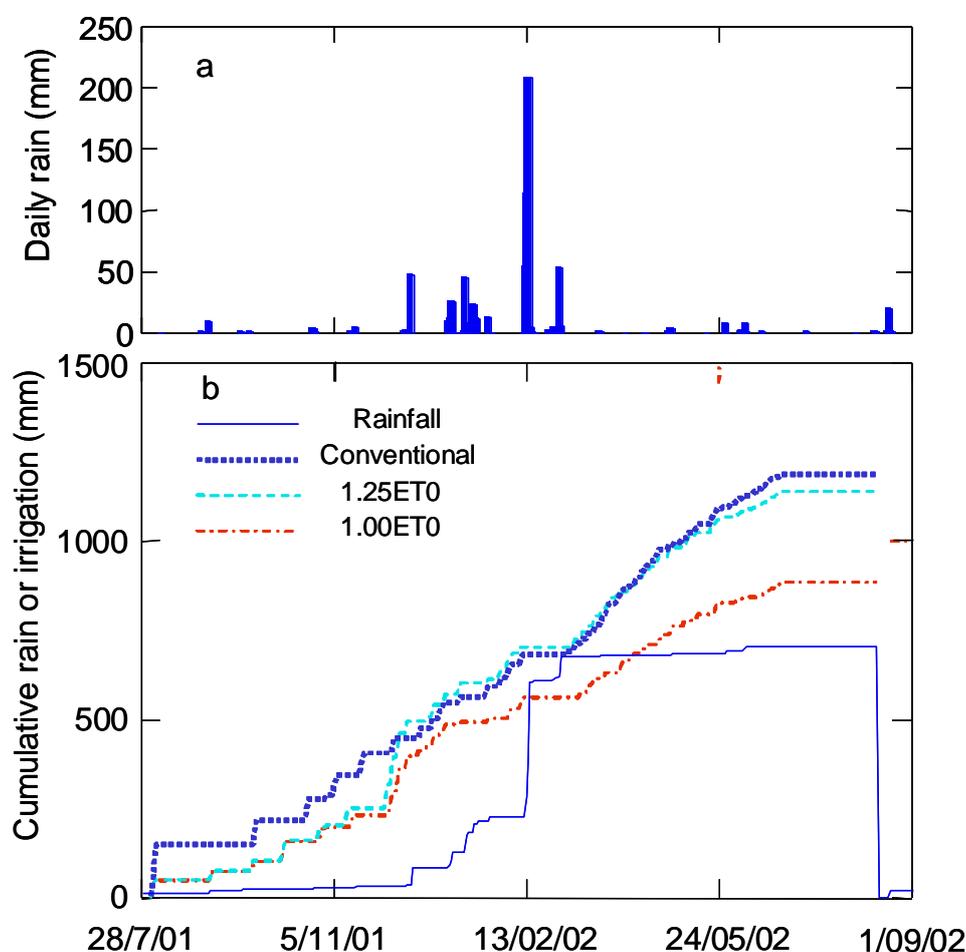


Figure 1. Daily rainfall (a) and cumulative rain or irrigation (b) for three irrigation scheduling treatments in the 2001/2002 scheduling experiment at Kalamia.

Results

December sampling (11/12/01)

In December when the crop was five months old the visual responses to irrigation was obvious and this was reflected in LAI and in total fresh above ground biomass (Table 1). Fresh biomass was 28 % greater in the 1.25ET₀ than in the 1.00ET₀ treatment and it was 58 % greater Conventional treatment than in the 1.00ET₀ treatment. It is interesting that this response was largely due to the additional water in the better irrigated crop. The dry matter content in the 1.00ET₀ treatment was 61 % greater than in the Conventional treatment and there was no difference between treatments in total dry biomass (Table 1). The low cane yield at this time may have also been affected by irrigation treatment (p=0.088) but there was no effect of irrigation on dry mass of the mature stem (Table 1). Green leaf mass was reduced in the 1.00ET₀ treatment compared to the other two treatments as would be expected from the LAI results. There were no other significant treatment effects.

Sampling at harvest (20/8/02)

The total number of leaves per stalk was reduced significantly in the 1.00ET₀ treatment compared to the other treatments however the number of green leaves per stalk was not affected by irrigation. Leaves senesce when the crop is under water stress but there was no evidence that the crop was more stressed in the low than in the high irrigation treatments. However no irrigation had been applied to any treatment since 26 June 2002 and it appears that the crop was drying off in a similar manner in all treatments. This is supported by similarities between treatments in regard to DM and sucrose contents of the mature stem (Table 1).

There was a downward trend with increasing irrigation in the number of sound stalks per m² but this was not significant. Cane yield was lower in the 1.00ET₀ treatment than the other two treatments but this too was not significant. Fresh and dry mass of individual cane stalks was reduced significantly by reduced irrigation thus there were opposing effects of irrigation on the growth of individual stalks and the number of stalks such that the net effect on yield was small. This could be associated with lodging which may have been worse in the higher than the lower irrigation treatments at some point in the duration of the experiment. The crop in all plots started to lodge after the storm in February and at harvest, lodging was slightly lower in the 1.00ET₀ treatment than the other treatments, however lodging angle was close to 90° in all treatments (Table 1).

Thus some crop attributes responded to the irrigation treatments but the responses in the most important attributes (cane yield and sucrose yield) were small. Yield differences at harvest between the 1.25ET₀ and Conventional treatments were, if anything, in favour of the 1.25ET₀ treatment.

Table 1. Summary of analysis of variance of results of plant sampling results on 11/12/01 (Sample 1) and 20/08/02 (sample 2). DMC = dry matter content, DM= dry mass, SC=sucrose content, SEM=standard error of the mean.

Crop component	Sampling	Treatments			Statistics		
		1.00ET ₀	1.25ET ₀	Conventional	SEM	P	LSD
Dead leaf number per stalk	1	0.2	0.5	0.5	0.1	0.130	
	2	22.4	24.8	24.5	0.7	0.101	
Green leaf number per stalk	1	7.4	8.0	8.2	0.4	0.399	
	2	7.1	8.1	7.1	0.6	0.423	
Total leaf number per stalk	1	7.7	8.6	8.7	0.4	0.171	
	2	29.5	32.9	31.5	0.6	0.024	1.7
Dead stalk number per m ²	2	1.3	0.6	1.0	0.2	0.099	
Sound stalk number per m ²	2	7.7	7.5	6.7	0.4	0.187	
Total stalk number per m ²	2	9.3	9.7	8.2	0.4	0.142	
Leaf area per gram DM (cm ² /g)	1	90.9	89.7	95.3	1.7	0.129	
	2	81.8	79.2	81.2	1.3	0.395	
Leaf area index	1	2.39	3.09	3.16	0.17	0.035	0.47
	2	2.57	2.74	2.58	0.24	0.850	
DMC of mature stem	1	15.5	15.1	14.8	0.2	0.131	
	2	33.3	33.7	33.1	0.9	0.896	
SC of stalks (DM basis)	2	49.9	48.0	48.1	1.9	0.734	
SC of stalks (FM basis)	2	15.9	16.1	15.9	0.2	0.718	
Cane yield (t/ha)	1	17.4	17.6	25.9	2.5	0.088	6.9
	2	105.6	117.8	114.9	6.5	0.426	
DM of mature stem (g/m ²)	1	584.4	305.5	377.5	205.4	0.631	
	2	3370.6	3983.8	3803.6	288.1	0.365	
DM of trash (g/m ²)	2	539	556	542	65	0.981	
DM of green leaf (g/m ²)	1	263.2	344.3	331.8	19.2	0.049	52.6
	2	314.0	345.9	316.0	24.9	0.620	
DM of total biomass (g/m ²)	1	1208.3	1165.6	1159.4	194.0	0.981	
	2	4489.1	5182.1	4930.7	319.8	0.364	
DM of total biomass minus trash (g/m ²)	1	1208.3	1165.6	1159.4	194.0	0.981	
	2	3950.0	4626.0	4388.2	295.8	0.329	
Sucrose yield (g/m ²)	2	1679.1	1903.0	1828.3	100.3	0.341	
Fresh total biomass (g/m ²)	1	3431	4385	5413	120	0.000	329
	2	12964	14270	13906	643	0.392	
DMC of total biomass (%)	1	34.6	26.7	21.5	5.4	0.296	
	2	34.9	36.2	35.5	1.5	0.841	
Fresh cane mass per stalk (g)	2	1374.4	1569.0	1712.7	65.6	0.030	180.2
Dry cane mass per stalk (g)	2	439.4	529.2	566.9	27.0	0.038	74.0
Dry total biomass per stalk (g)	2	585.4	691.2	735.2	35.3	0.058	96.9
Lodging angle (deg from vertical)	2	82.5	87.0	88.8	2.3	0.226	

Soil water content

Soil water content at all depths declined prior to the first sampling in December (Figure 2). Water extraction at depth was most pronounced in the 1.00ET₀ treatment. Thus despite the exploitation of deep soil water by this treatment in the preceding crop (first ratoon) there was still a considerable amount of water available at depth for extraction in the second ratoon crop. Irrigation applied to refill the top 500 mm of soil, penetrated at least to

375 mm in all treatments and to 750 mm in the case of the 1.00ET₀ and 1.25ET₀ treatments. Soil water content at greater depths increased only after the storm in February (Figure 2). After this storm there was little difference in water content between treatments and there was a general increase in soil water content in all treatments and at all depths down to 750 mm indicating that all irrigation treatments were more than adequate for crop water demand after December 2001. This conflicts with data and conclusions of the previous experiment where the 1.25ET₀ schedule was considered as a good match for crop water required to achieve maximum yield. It is likely that severe lodging after the February storm reduced yield and crop water requirement because of disruption to the leaf canopy.

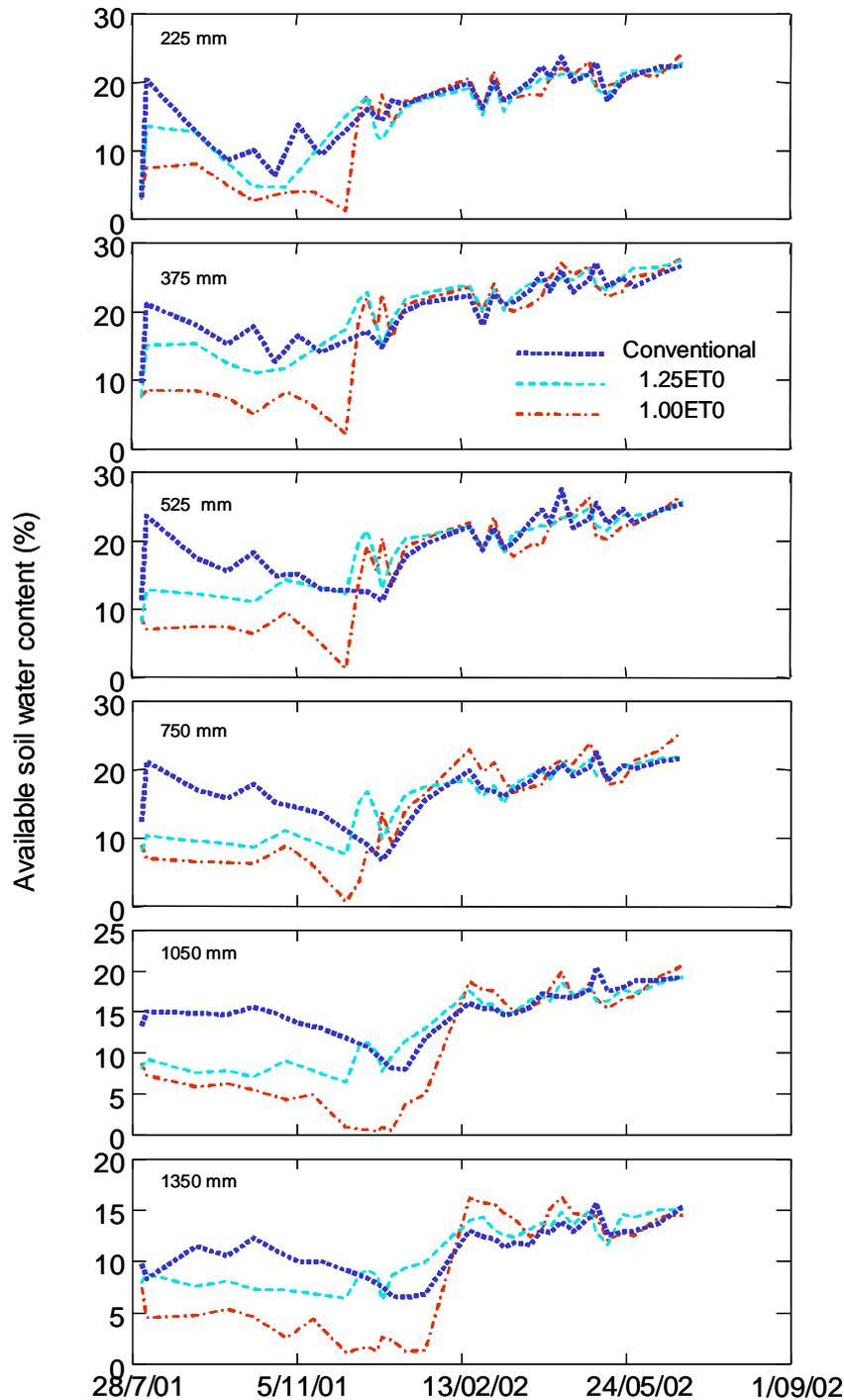


Figure 2. Available soil water content at successive soil depths for 1.00ET₀, 1.25ET₀ and Conventional treatments, determined with the neutron moisture meter.

Simulation analysis

Simulation analysis confirmed that biomass yields were well below potential and well below expected yields for the Conventional and 1.25ET₀ treatments when the crop was harvested (Figure 3). These results bear some resemblance to data obtained on reduced yields and reduced water use after the wet season in the Ord. In the Ord, irrigation scheduling has been adjusted to match reduced water use at this stage even though an explanation for these reductions has yet to be developed. There is mounting evidence in the Burdekin that yield accumulation and water use is markedly reduced after lodging and it is likely that irrigation scheduling can be adjusted to avoid wasting water during this stage.

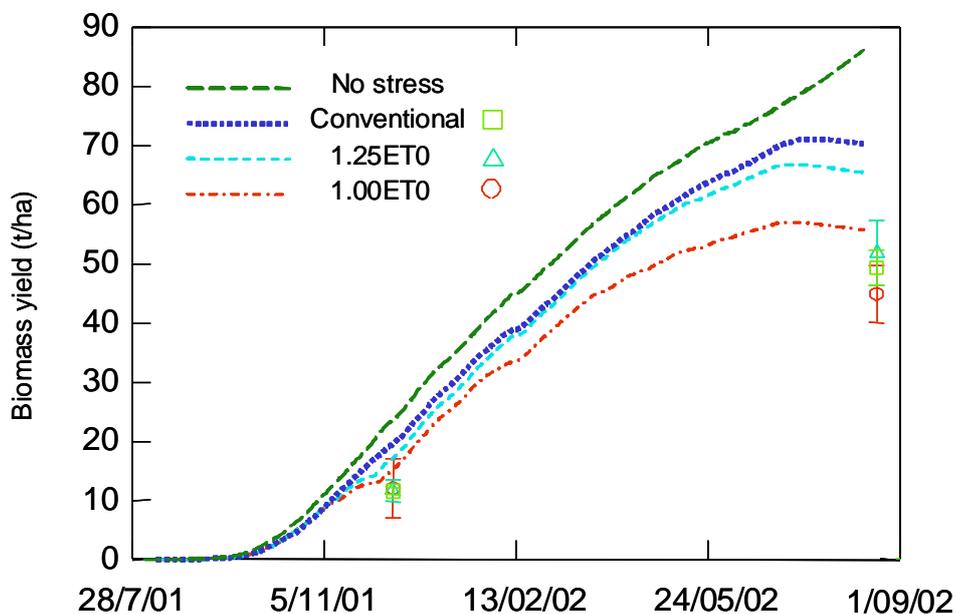


Figure 3. Measured biomass (symbols) and simulated biomass (lines) for three irrigation scheduling treatments in the 2001/2002 scheduling experiment at Kalamia.

