Sugar Research and Development Corporation

Final Report

Project No CSR22

Project Title:	Best-practice irrigation management to maximise profitability and ensure sustainability in the Ord Sugar Industry
SRDC Program:	Program 2: Crop Management
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Best practice irrigation management

EXECUTIVE SUMMARY

The Ord Sugar industry was established in 1995 with the commissioning of a sugar mill and the first full season of commercial production was in 1996. It is now a major industry in Stage 1 of the Ord Irrigation Area, currently occupying over 4000 hectares and producing around 60,000 tonnes of raw sugar annually for export.

The climatic conditions in the Ord impose a high water requirement for sugarcane crops. Growers face a considerable challenge in meeting that requirement whilst maximising their profitability and minimising drainage losses and potential impacts on the environment. Groundwater levels have risen substantially in the 30 years since the start of irrigation in the Ord. Consequently the development of appropriate irrigation practices for sugarcane is a key requirement in the management of rising water tables and in the sustainability of Ord sugarcane production.

The first step in developing best practice irrigation management was to gain a better understanding of the range of irrigation practices being used by the industry at the beginning of the project. A survey conducted to benchmark irrigation practices used on the 1995/96 sugarcane crop indicated very high rates of annual water application, making the development of irrigation practices that maximise profitability and minimise groundwater accessions a key priority for the Ord sugar industry.

Withholding irrigation prior to harvest, termed drying-off, is often used to dry out fields and increase sugar content, although responses can be highly variable. To examine this concept in the Ord, treatments were imposed on 3 crops of sugarcane in 1997 and four in 1998 by withholding irrigation for various lengths of time prior to harvest. Results indicated minimal responses to drying-off for periods of up to 80 days, with no increase in sucrose content of the cane.

A trial was established in 1998 to quantify the yield responses to different irrigation schedules and assist in the development of irrigation practices that not only maximise sugar yields but also improve the efficiency of irrigation water use and stabilise rising water tables. Surprisingly, there was little response to the treatments imposed which represented the extremes in likely irrigation schedules.

The pattern of biomass accumulation in both the drying-off and irrigation scheduling trials indicated a slow-down in crop growth in the later stages of crop development. Comparisons with other areas showed that early growth rates were not much lower than those measured in the Burdekin but that later growth was significantly slower. Measurements of crop water use confirmed that high rates of water use occurred before the wet season but much lower rates relative to evaporation occurred after the wet season. Clearly there appears to be a close relationship between the pattern of crop biomass accumulation and the rate of crop water use with a marked slow-down in both occurring following the onset of the wet season. This has important implications for irrigation water management guidelines with more frequent irrigations being appropriate during the hottest part of the year leading up to the wet season and much less frequent irrigations being needed after the wet season, which also appears to be a critical period for accessions to the water table. Measurements of water extraction on a range of soils indicated very high levels of plant extractable soil water. This provides additional support for much longer intervals between irrigations but possibly more water applied at each irrigation.

Crop modelling using the APSIM Sugarcane model and the experimental data gathered in this project was used to develop irrigation guidelines for different conditions. The model had to be reconfigured based on the slower growth rates during the later stages of crop development. Another model, the Surface Irrigation model (SIRMOD) was used to simulate the requirements for achieving optimum water application efficiency for furrow irrigation of the cane crop. Data collected from different furrow-irrigated bays of sugarcane were used to configure SIRMOD so that it simulated irrigation events over a range of different conditions in the Ord. It was used to develop 'look up' tables indicating expected irrigation application efficiencies when factors such as moisture deficit, furrow inflow rate, irrigation duration, furrow length and furrow shape were varied. These guidelines for optimising irrigation application efficiency are amongst the most comprehensive anywhere in the Australian sugar industry.

Best practice irrigation guidelines, which maximise profitability and minimise losses of water, are now available to the Ord sugar industry. They include recommendations on irrigation frequency, soil moisture at irrigation, tail water flow, furrow shape, optimum row length and management of deep drainage. However, there remains considerable scope for growers to make further improvements to their irrigation management practices and tailor their applications more closely to the specific requirements of their crops and soils, and it will not be until this occurs that regional water tables in the Ord will start to stabilise.

The following benefits are likely to arise from this project and impact on the sugar industries in the Ord and in eastern Australia:

- better matching of irrigation applications to crop requirements leading to reduced use of irrigation water and reduced accessions to groundwater;
- improved likelihood of meeting future water licensing requirements and targets;
- reduced losses of irrigation water through deep drainage and tailwater runoff;
- longer viability of laser levelled cane blocks and reduced siltation of tailwater drains;
- improved profitability with less frequent irrigations through reduced irrigation costs;
- improved social impact through less time spent irrigating;
- reduced pressure on irrigation infrastructure;
- stabilisation of groundwater tables;
- reducing pressures from environmental lobby groups;
- application of knowledge gained from this project to other irrigated sugarcane areas such as the Burdekin and to other irrigated crops grown in the Ord.

1. INTRODUCTION AND PROJECT BACKGROUND

The Ord River Irrigation Area

The Ord River Irrigation Area (ORIA), which was developed in 1962 with the construction of the Diversion Dam which led to the formation of Lake Kununurra, comprises approximately 13,000 ha of irrigable soils. In 1973, the building of the Ord Dam that created Lake Argyle ensured a water supply for an irrigation project of more than 50,000 ha. The irrigation system was constructed to take advantage of abundant supplies of water with a network of channels fed by a single main channel delivering water to farms.

Stage 1 of the ORIA consists of around 10,000 ha of land on the Ivanhoe Plain with mainly cracking clay soils of the Cununurra Series. Areas between the plain and the river are sandier soils of the river levee and the Pago and Cockatoo Sands between the plain and the nearby hill systems. Some areas of very heavy Aquitaine clay soils are located on the flatter margins of the main Ivanhoe Plain. A further 2000 ha of land on the Packsaddle Plain includes most of the soil types found on the Ivanhoe Plain as well as significant areas of medium textured red clay soils of the Packsaddle Series. More than 60% of the ORIA is underlain by sand and gravel beds from the old channel of the Ord River. These conduct water well and form extensive interconnected aquifers beneath the irrigated areas of both the Ivanhoe and Packsaddle plains. The water in these aquifers usually has low levels of dissolved salts.

Following extensive cropping trials throughout the 1940's and 50's, the initial irrigation farming system was based on cropping cotton over the wet season. Farms of about 240 ha were released in the early 1960's and these were serviced with irrigation supply points and drainage outlets as required. Conditions were placed on the development of the farms to encourage rapid development of the irrigation land. In the 1960's and early 1970's, cotton was the main crop grown in the irrigation area. The cotton industry closed in 1974 and the area under crop declined significantly for a number of years. Towards the end of the 1980's horticulture was introduced and high value crops that could supply the domestic market out of season were adopted such as cucurbit crops, bananas and a range of small crops. Profits from these high value crops enabled other crops such as sugarcane to be grown and resulted in all of the available irrigation land being brought into production.

The Ord Sugar Industry

In late 1994 CSR Ltd., with the Ord River District Cooperative as a minor shareholder, commenced construction of a sugar mill. The sugar mill is a low cost, small capacity factory based on modern technology and low labour requirements. It was designed to be able to process a total crop of 560,000 tonnes at a crushing rate of 120 tonnes cane per hour. The first cane was processed in late 1995 and the first full season of crushing was in 1996. This was the first commercial sugar industry established in the Ord even though sugarcane had been suggested as a suitable crop for many years. The system of sugarcane production employs furrow irrigation methods that are suitable given the low cost of irrigation water compared with other irrigated cane areas in Australia. The cane growers in the Ord were already established farmers growing a range of other irrigated crops and so furrow irrigated sugarcane fitted easily into the farming system. A strong history of highly efficient irrigation water use had not been established in the area as the provision of water had never been regarded as being limited or a significant cost.

The sugar industry has not been able to achieve either the yield or CCS targets initially set in the planning phase and the production of high yielding and high CCS crops remains a challenge for the industry to ensure its future viability. The expectation, when commercial sugarcane production began, was of large crops yielding in excess of 160 tonnes cane per hectare and with a high sugar content, comparable with the Burdekin region. Whilst cane yields have been highly variable but with some blocks reaching target yields the low sugar content and purity of Ord cane, particularly early in the season, has been the most surprising and disappointing aspect of commercial sugarcane production. Consequently a major reason for initiating the current research project was to examine different irrigation management strategies and find ways of achieving high cane and sugar yields in conjunction with efficient water use and negligible environmental impacts.

Review of previous irrigation work conducted with sugarcane in the Ord

Prior to the Ord development being funded, sugarcane had been identified as a potential crop for the region but repeated examination of sugar as a commercial crop and significant government and industry research commitments during the 1950's and 60's failed to result in a commercial industry (Gardiner, 1998).

Early sugarcane research in the Ord River District occurred in three distinct periods:

1. The first period of work from 1950 - 1957 was conducted by the CSIRO at the Kimberley Research Station, Kununurra
2. In the second period from 1964 - 1968, CSR conducted further research into sugarcane production at Kimberley Reseach Station.
3. In the third period, from 1974 - 1982, work was conducted jointly by the Department of Agriculture and the Bureau of Sugar Experiment Stations on a commercial scale pilot farm.

The first irrigation trials with sugarcane in the Ord were conducted by CSIRO in the 1950's at the Kimberley Research Station and were reported by Lee *et al* (1963). Based on measurements of cane growth in relation to moisture supply and visual observations of leaf water stress, Lee *et al* concluded that in the absence of rain an irrigation frequency of 10-14 days was probably adequate for good cane growth. Subsequently CSR conducted an irrigation scheduling trial over a period of three years using the sugarcane varieties Trojan and Pindar. The four irrigation treatments in the plant crop were:

1. Irrigating every 10 days
2. Irrigating when the stalk extension of Pindar fell below 5mm/day
3. Irrigating every three weeks
4. Irrigating when the crop appeared stressed.

From the experimental data available in Gallagher (1986), it is impossible to establish whether there were significant responses to the different irrigation treatments. Plant cane results showed no apparent differences in cane yield for the first three treatments but reduced yields for the fourth treatment.

In first and second ratoons treatments were changed to:

1. Irrigating every 7-10 days
2. Irrigating every 10-14 days
3. Irrigating every 2-3 weeks
4. Irrigating when the crop appeared stressed.

Again yields appeared to be lower in the fourth treatment. No apparent CCS differences occurred between any of the scheduling treatments imposed.

Further research on sugarcane was conducted in the Ord from 1975-82 (Cox and Chapman, 1985), but with ample low priced irrigation water available little attention was paid to irrigation frequency or water management. Gallagher (1986) reported the results of an irrigation trial with six different treatments established on the Pilot Farm using the sugarcane variety Trojan. In the plant crop the treatments included two different irrigation schedules based on different pan factors and further schedules were imposed in the first and second ratoon crops using a range of different pan factors. The results suggest that there were no apparent differences in cane yield or CCS. However the BSES report (BSES, 1982) mentions that the variety in this trial was badly affected by top rot. The conclusion from this trial work is that "the experiment contributed little towards providing preliminary recommendations for frequency of irrigating sugar cane on Cununurra clay soils" (Gallagher, 1986).

Much of the early irrigation scheduling work with sugar in the Ord was inconclusive with little or no response to either irrigation frequency or to drying off strategies. Consequently the generally accepted schedules of 25-30 irrigations per crop year (watering every 10-14 days) were still the broad recommendation when the present commercial sugar industry began in 1994.

Groundwater

In common with most other irrigation areas throughout Australia and the rest of the world, groundwater levels have risen substantially in the 30 years since the start of irrigation in the ORIA and in some areas are so close to the surface that they require remedial measures. Groundwater at or near the surface in irrigation areas can reduce crop yields (and sugarcane in particular) not only through waterlogging but also through salinity in the root zone and sodicity from high sodium levels in groundwater causing soil structure problems. A good understanding of the effects of irrigation on the groundwater regime is therefore important for sustainable agriculture in the Ord River Irrigation Area (O'Boy *et al,* 2001).

Groundwater levels have been monitored since the inception of the Ord irrigation project. Groundwater levels have continued to rise at alarming rates, of around 20cm per year over a significant proportion of the irrigated area. Due to the high water requirements of sugarcane and the significant area already under production or proposed for Ord Stage 2, sugarcane could potentially have a major impact on groundwater accessions. Concerns about an acceleration of rising groundwater levels associated with irrigated sugarcane production were a major reason for initiating this program of research. The sustainability of the Ord sugar industry will depend on the implementation of appropriate management practices which are compatible with both production and groundwater requirements.

More recently, a groundwater management committee was formed by growers to develop and implement a land and water management plan for the area. The Ord Land and Water Management Plan was published in 2000 and includes goals for groundwater, irrigation efficiency and surface water quality. These include:

1. Reducing ground water levels to greater than 2 metres from the surface across the whole irrigation area within five years;
2. Holding the quality of groundwater at or above the quality in 2000;
3. Improving irrigation management to achieve 65% average annual water use efficiency on all irrigation farms within five years;
4. Reducing sediment loads in tail water by 40% within five years.

Development of appropriate irrigation management practices for sugarcane will be a key requirement in the management of rising groundwater levels and in the sustainability of Ord production. Expansion of the Ord sugar industry into environmentally more sensitive areas adjacent to the existing irrigation area will also be dependent on the improvement of irrigation practices and a better understanding of water table management.

Climate

Climatic conditions dictate a high water requirement for sugarcane growing in the Ord (Robertson *et al,* 1997), and growers face a considerable challenge in meeting that requirement whilst maximising profitability and minimising deep drainage losses and potential impacts on groundwater and the environment. The unique climatic conditions and production system in the Ord irrigation area, with a long (30 week) harvest season, present new challenges to profitable and sustainable sugarcane production in Australia. With the establishment of a sugar industry in the Ord, important questions have been raised as to what is the potential sugar production per hectare given the climatic conditions in the region and what is the irrigation water requirement to reach this potential. Such information is essential not only for devising best practice irrigation management strategies for on-farm application but also for assessing the present and future allocation requirements for irrigation water.

In an earlier SRDC project in the Ord, Muchow *et al* (1996) conducted a desktop study of potential annual sucrose yields and irrigation water requirements using the APSIM sugarcane crop simulation model for Kununurra, Ayr and Ingham. This indicative simulation analysis suggested average "potential" cane yields over a plant crop and four ratoons of 239 tonnes cane/ha for Kununurra, 201 tonnes cane/ha for Ayr and 191 tonnes cane/ha for Ingham. It also suggested an extremely high irrigation water requirement in the Ord which was more than double that in the Burdekin environment. The model predictions highlighted the need for field data on potential crop yields and crop water requirements under Ord conditions for sugarcane crops ratooned at different times of the year. Whilst irrigation scheduling guidelines have already been developed for different sugarcane areas in Queensland, it is unlikely that they can be directly applied to the Ord with its combination of very different climatic conditions (very high temperatures and evaporation) and a different suite of soil types.

Allocation and costing of irrigation water

The current allocation of water by the Ord River Cooperative for surface irrigated crops is 17 ML/ha. Irrigation water is metered by means of a Dethridge wheel from the supply channels to a head ditch on each property. Current water costs for broad-acre crops are extremely low: $2.44/ML + $75/ha/year fixed charge.

Whilst at present only a small proportion of the available water resource in the Ord is being utilised, plans for new irrigation developments that will maximise the use of available water are now underway and this has introduced the need for a Water Allocation Plan. A draft Water Allocation Plan has been under review since 1999 and this will specify the maximum amount of water that can be diverted per irrigation water year by the Ord Irrigation Cooperative. This amount will be a function of the current wet season rainfall and the procedures for its calculation specified in the water distribution operating strategy. The operating strategy will specify water quality, water use and efficiency targets and will build on the community's commitments under the Ord Land and Water Management Plan.

2. PROJECT OBJECTIVES

This project sought to benchmark current irrigation management practices in the Ord River Irrigation Area and to develop improvements to these that firstly maximised sucrose accumulation by defining appropriate "drying off" practices close to harvest; secondly that maximised profitability by matching irrigation applications with crop water requirements for different harvest times throughout the April to November period; and thirdly that stabilised rising water tables and improved the efficiency of irrigation water use.

The objectives of the project, that were set at the outset of the project, were as follows:

1. To benchmark current irrigation practices in the Ord Irrigation Area and hold an Industry workshop to define research priorities and the components of best practice irrigation management.
2. To conduct on-farm research to quantify the impact of different irrigation practices on productivity, water use efficiency, profitability and groundwater management for the Ord sugar industry.
3. To collect yield accumulation and complementary climate, soil and crop data and use these to test a sugarcane crop growth simulation model tailored to Ord conditions.
4. To use field experimentation, databases and sugarcane simulation models to identify best production practices related to irrigation management with the emphasis on maximising profitability by matching irrigation applications with crop schedules for different times of harvest.
5. To develop and promote irrigation management strategies that optimise the long-term profitability of the Ord Sugar Industry and keep accessions to the regional water table at a level required for sustainability.

The project was reviewed by SRDC on 28-29 October 1997 at the Frank Wise Research Institute. The review team recommended that the project should continue into the expanded experimental phase envisaged at the start of the project. They made a number of recommendations regarding specific objectives of the project:

- Support was given for the appointment of an Industry Development Officer to assist with the development and promotion of best practice irrigation guidelines.
- Best practice irrigation management needs to take into account soil variation across the irrigation area and local variations in clay content and soil depth can influence soil water extraction by the crop.
- Initial experimental results from different experiments to quantify water application efficiencies appear to be highly variable and care needs to be taken in the choice of suitable cane blocks for this work.
- Although crop nutrition was outside the scope of the project, productivity variation may be related in part to nutritional limitations. Strategic monitoring of nutrient levels in both soils and plant tissues should be considered at experimental sites.
- Project review and planning meetings should provide greater opportunity for dialogue and interaction. Consideration should also be given to coordinating the review and planning meetings to coincide with mid season and end of season sugar industry review meetings.
- The formation of small focus groups of growers should be considered to facilitate the adoption, evaluation and demonstration of improved practices and the proposed Industry Development Officer should be encouraged to work closely with these groups.

3. PARTIES INVOLVED AND LINKS WITH OTHER INITIATIVES

The project was set up as a research partnership between CSR Technical Field Department, CSIRO Tropical Agriculture (now CSIRO Sustainable Ecosystems), Agriculture Western Australia and SRDC. A key feature of the project was participatory on-farm research involving the Ord Sugar Industry, the research partners and SRDC. An important component of this participatory process has been the involvement of the Ord cane growers and Ord Industry Board in the planning and development of research activities. Research meetings were held twice a year throughout the course of the project to present results to Industry and progressively develop best management irrigation practices in collaboration with growers as appropriate information became available.

This project when established was closely related to research being conducted by CSIRO Tropical Agriculture and CSR in the Herbert and Burdekin districts aimed at achieving efficient use of water and nitrogen in the sugarcane production system (SRDC projects CSC4S, 7S, 16S, 18S and 21S). Immediate linkages were established between this project and the research being conducted in projects CSC16S "Efficient use of water resources in sugar production: A physiological basis for crop response to water supply" (work mainly in the Burdekin district) and CSC18S "Efficient use of water resources in sugar production: Optimising the use of limited water under supplementary irrigation" (work mainly in the Herbert district). It also had close linkages to a BSES project in the Burdekin focussed on improving water application efficiency – BS90S "Increased productivity through better design of irrigated cane fields". More recently, close links have been established with the irrigation risk management work being conducted in the Burdekin (project CTA038).

The project was also closely linked to an Ord project initiated in 1995: WAA1S "Water table monitoring in the Ord River Valley" (Nulsen and Sherrard, 1999). This was a component of a larger initiative by Agriculture Western Australia and the WA Water and Rivers Commission to examine and implement appropriate options for the management of rising water tables in the Ord River Irrigation Area. This linkage was regarded as being critical to ensure that the options implemented to manage the rising water tables are consistent with the requirements for maximising Ord sugar industry profitability. The project also followed on logically from part of SRDC project ORD004S in which a desk-top analysis was conducted of the production potential and irrigation water requirements of sugarcane crops in the Ord using the APSIM sugarcane growth model and 80 years of historical weather data (Muchow *et al*, 1996).

4. METHODOLOGY

A partnership approach was adopted in this project to fund and service the needs of the Ord Sugar Industry. The partnership includes the Ord sugarcane growers, the Ord Sugar Industry, three research organisations (Agriculture Western Australia, CSIRO and CSR) and SRDC. An important part of this partnership approach has been the involvement of the Ord growers and Industry in the planning and development of research activities and in the interpretation and adoption of research results.

The methodology adopted in this project involved the following sequence of activities:

- Development of research partnership and preliminary consultation with growers and Industry representatives
- Setting up automatic weather stations and collection of data on crop management, weather, soils and crop yields
- Benchmarking of current irrigation practices using questionnaire surveys and crop logs of individual fields
- Setting up instrumented experimental sites for the collection of data on yield and sugar accumulation, soil and climatic conditions, and on water use and water table levels
- Conducting two sets of on-farm experiments which focus on different irrigation management strategies aimed at maximising sucrose accumulation by defining "drying off" practices close to harvest, maximising profitability by matching irrigation application with crop schedules for different harvest times, and stabilising rising water tables and improving the efficiency of irrigation water use
- Conducting crop simulation analyses using the APSIM-Sugar simulation model with data from the on-farm experiments to explore options for improved irrigation management
- Reviewing research on irrigation water application efficiency and conducting experiments to develop ways of using irrigation water more efficiently
- Appointing an Industry Development Officer to assist with the collection of experimental data on farms and to work closely with growers in developing more profitable and sustainable irrigation management practices.

Further details of methodology are presented in the sections of this report describing the individual components of the project (Sections 5 – 11).

5. BENCHMARKING GROWERS' IRRIGATION PRACTICES

Introduction

A first element in addressing and ensuring best practice irrigation management in the Ord sugar industry was to obtain a full understanding of the range of current irrigation practices. To achieve this, a survey was undertaken to benchmark irrigation practices in the Ord Sugar Industry during the first year of commercial sugarcane harvest (1995-96 crop) in the Ord (Wood *et al.*, 1998). The purpose of such a benchmarking activity was to identify those areas where potential improvements could be made and to guide decisions on research direction and investment to ensure that maximum benefit is delivered to the industry. It also provided a benchmark against which the impact of this research could be evaluated at a later date. This section reports on the key findings of the survey and identifies options and research needs for further improvements in irrigation practice in the Ord sugar industry.

Benchmark measures of irrigation practice

The following measures were used for benchmarking irrigation practices. These measures would apply equally well to other fully irrigated sugarcane areas in Australia:

- Water applied per irrigation
    - length of run, siphon size, duration of irrigation and tail water discharge
- Water applied per crop cycle
    - irrigation frequency at different times of year, length of drying-off, method of irrigation scheduling
- Tonnes of cane and sugar produced per ML water applied
- Tonnes of cane and sugar produced per ML water used by crops
    - irrigation application efficiency, rainfall effectiveness
- Tonnes of cane and sugar produced per hectare, per annum
- Cane sugar content (CCS, Pol)

Methodology

The survey included 13 growers and 27 blocks of sugarcane and was conducted by grower interviews during the 1995/1996 growing season. Yield data were available for 26 blocks, all of which were plant cane with cane yields between 117 and 210 tonnes cane/ha. These represented 438 ha and 79,823 tonnes of cane. Since the survey was conducted retrospectively, some of the variables are likely to be "best estimates" rather than absolute measurements. In particular, growers had very little scope to estimate irrigation application efficiency.

The total water applied to each block and crop water use was calculated using the following methods:

1. Dates, times and flow rates in ML/hr were obtained from the Ord Irrigation Cooperative Limited for each block;
2. Growers supplied data on the number of hours water was applied per irrigation on each block;
3. Growers supplied data on the number of irrigations applied over the life of each crop, thus allowing the total amount of water applied in ML/ha to be calculated for each crop;
4. The amount of water applied per annum was calculated using data supplied by growers on the age of the crop;

5. Crop water usage was calculated by multiplying the total water applied by the irrigation application efficiency estimated by the growers, and adding effective rainfall. The estimated application efficiency took into account the losses due to runoff down tail drains and deep drainage losses through the soil profile. It was assumed that 72% of total rainfall was effective in meeting crop water requirements (Muchow *et al*, 1996). Of the 827 mm annual rainfall in 1995/96, the amount of effective rainfall was calculated as 595 mm.

Mill data for each block were used to calculate t cane per harvested ha. Since growers in the Ord are paid on Pol % cane, ccs for each block was derived using the relationship shown in Figure 5.1. This relationship was obtained using data from every rake of cane harvested in the ORIA in 1996 where both Pol and Brix were measured. Mill Pol and ccs data were adjusted for undetermined gains in the milling process using data derived from the CSR Summary and Season Forecast Report. Sugar yield was calculated as the product of cane yield and CCS/100, as in the Queensland sugar industry.

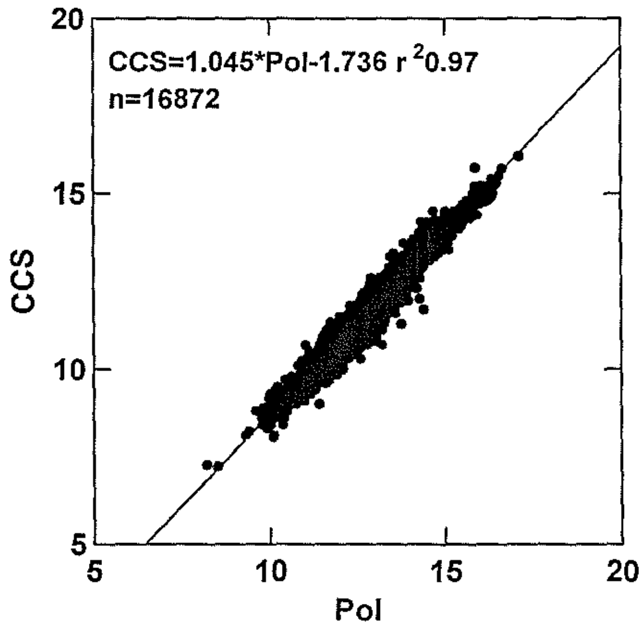


Figure 5.1. Relationship between CCS and Pol on samples measured during 1996 in the ORIA.

The mean and range of the different variables were calculated, and compared with the block that achieved the highest sugar yield (e.g. Table 1). The survey results were compared with the results of preliminary model predictions of crop water requirements.

Results and Discussion

Analysis of the survey results indicates that a wide range of irrigation practices are employed by sugarcane growers in the Ord. Table 5.1 summarises key water management data which have been collected, estimated or calculated from the survey. The data support the results of preliminary analyses using the APSIM sugarcane model which suggested that sugarcane crops in the Ord have a much higher irrigation water requirement than those in other sugarcane districts (Muchow and Keating, 1998). A huge range in the number of irrigations, amount of water applied and length of drying off period was recorded. This suggests that growers are using a range of water management strategies to achieve profitable sugarcane production and would benefit from assistance in developing the most appropriate strategy to achieve the most efficient and profitable use of irrigation water.

The total water applied to each crop is extremely high ranging from 20 to over 80 ML ha^{-1}. The amount applied to the block with the highest sugar yield is about the same as the mean. Estimates of irrigation water application efficiency were supplied by growers for 15 of the 27 blocks surveyed and these ranged from 60 to 75%. Comparisons with other sugarcane producing districts are difficult as very little benchmark irrigation data are available from other areas apart from recent work on irrigation water application efficiency in the Burdekin district (Shannon and Raine, 1996; Raine and Bakker, 1996). In these studies, irrigation application efficiency varies with soil type and length of irrigation run, with efficiencies on low infiltration cracking clay soils in excess of 70%. In an earlier study with kenaf in the ORIA, Muchow and Wood (1981) measured application efficiencies ranging from 50 to 85% on Cununurra clay, with application efficiency decreasing with an increase in irrigation frequency. Fortnightly irrigation schedules resulted in application efficiencies close to 70%. In that study, significant infiltration of water into the soil still occurred when lateral wetting of the soil surface was complete and the flow of water from channel to field was stopped. Water application efficiency with flood irrigation on Cununurra clay for maize production ranged from 67 to 86% (Sherrard *et al.*, 1991). There is a clear need to obtain better estimates of both runoff and deep drainage by conducting field measurements in the ORIA.

Table 5.1. Total water applied during irrigation.

Measure	Mean	Range	Value for block with highest sugar yield
Total number of irrigations	27 (27)$^{+}$	15 - 42	37
Length of run (m)	489 (27)	250 - 1100	1100
Total water applied (ML ha^{-1} crop^{-1})	40.6 (26)	20.8 - 83.1	39.8
Irrigation application efficiency (%)$^{\#}$	70 (15)	60 - 75	65
Total crop water use (ML ha^{-1} crop^{-1})**	31.9 (15)	24.2 - 45.3	31.8
Crop water use efficiency (t cane ML^{-1})**	6.1 (15)	3.9 - 7.6	6.6
Drying-off before harvest (d)	36 (27)	7 - 82	42
Annual water applied (ML ha^{-1} yr^{-1})	32.5 (27)	15.3 - 53.8	34.1
Annual crop water use (ML ha^{-1} yr^{-1})**	27.5 (15)	22.7 - 41.0	28.1

$^{+}$ Number of blocks with available data indicated in brackets; $^{\#}$ Grower estimate only; **Assumes effective annual rainfall of 595mm and estimated application efficiency accounts for runoff and drainage losses.

Crop water use was calculated by assuming that 72% of total rainfall was effective in meeting crop water requirements (Robertson *et al.*, 1997) and using the estimated application efficiency. The average crop water use per annum was 27.5 ML ha^{-1}, with values ranging from 22.7 to 41 ML ha^{-1}. Preliminary simulation analyses have suggested a crop water requirement of 29.3ML for a 212 t cane ha^{-1} twelve month sugarcane crop growing under ideal conditions in the ORIA (Muchow *et al.*, 1996). Whilst the crop simulations have not been validated for ORIA conditions, further model runs (Robertson *et al.*, 1997; Muchow and Keating, 1998) suggest that these estimates are realistic and the maximum likely. Consequently, it is unlikely that the high value of 41 ML ha^{-1}, at the upper end of the range of estimated annual crop water use, is correct. This is most likely to be due to overestimates of application efficiency. This further highlights the need to obtain better estimates of application efficiency. Calculated values for crop water use efficiency for cane crops harvested in the 1996 season (mean 6.1 t cane ML^{-1}, and 6.6 t cane ML^{-1} for the block with the highest sugar yield) are similar to the simulated crop water use efficiency using 81 years of climate data of 7.24 t cane ML^{-1} for a 12 month ratoon crop grown under non-limiting conditions (Muchow *et al.*, 1996).

From the survey data, there was no clear relationship between sugar yield and the amount of irrigation water applied (Figure 5.2). With such variation, it is not possible to use the survey data to identify "best-bet" strategies for maximising sugar yield in relation to irrigation application. Rather this survey has highlighted the need for field experimentation coupled to simulation modelling to explore the relationship between sugar yield and water applied in order to identify best-practice irrigation management.

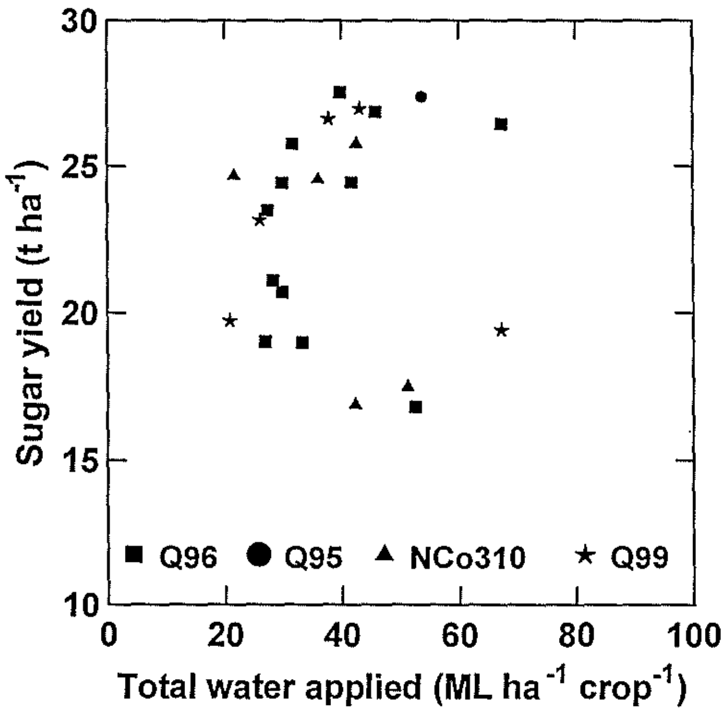


Figure 5.2. Variation in sugar yield for four varieties with different amounts of irrigation water

Data on irrigation frequency and the number of irrigations (Table 5.2) show that the climatic conditions of the Ord River area demand very frequent irrigations, particularly in the hotter parts of the year. Whilst mean data for the frequency of irrigation did not change much over the year, irrigation frequency on the highest yielding block increased to weekly irrigations for the August to November period.

Table 5.2. Frequency of irrigation and number of irrigations.

Months	Frequency of irrigation (days)			Number of irrigations		
	Mean	Range	Best Block	Mean	Range	Best Block
Apr. 95 - Jul. 95	15 (22)$^+$	10-21	14	5 (22)$^+$	2-9	4
Aug. 95 - Nov. 95	14 (26)	7-21	7	9 (26)	6-15	15
Dec. 95 - Mar. 96	13 (24)	7-20	7	6 (27)	4-9	9
Apr. 96 - Jul. 96	13 (27)	7-20	10	7 (27)	3-15	9
Aug. 96 - Nov. 96	14 (13)	0-30	-	4 (12)	0-10	-

$^+$ Number of blocks with available data indicated in brackets

Considerable wastage of irrigation water is suggested by the data on tail drain flow in Table 5.3. The need for such frequent irrigations and the costs and feasibility of applying irrigation water in this way require further investigation. Furthermore the need to maximise profitability rather than productivity and the need to minimise accessions to the ground water need to be considered in developing best-practice irrigation management.

Table 5.3. Duration of irrigation and tail drain flow.

Months	Duration of irrigation (hours)		Time to reach tail drain (hours)		Duration of tail drain flow (hours)	
	Mean	Range	Mean	Range	Mean	Range
Apr. 95 - Jul. 95	20 (22)$^+$	12-24	14 (18)$^+$	3-20	7 (20)$^+$	3-10
Aug. 95 - Nov. 95	20 (26)	12-24	15 (22)	3-20	7 (24)	3-17
Dec. 95 - Mar. 96	20 (27)	12-24	15 (23)	5-20	7 (25)	3-17
Apr. 96 - Jul. 96	20 (27)	12-24	15 (22)	5-20	7 (24)	3-17
Aug. 96 - Nov. 96	20 (12)	12-24	15 (11)	7-20	8 (10)	4-17

$^+$ Number of blocks with available data indicated in brackets

The very large variation in the amount of water applied to sugarcane crops in the Ord is confirmed by the data in Table 5.4. The amount applied to the highest yielding block is well below mean applications. Also, the average amount of water applied per irrigation is surprisingly high for the April to November period when crops would have been relatively small. This suggests that application efficiencies may have been considerably lower than the 60-75% estimated by growers (Table 5.1).

Table 5.4. Water applied.

Months	Water applied per irrigation (ML ha^{-1})			Total water applied (ML ha^{-1})		
	Mean	Range	Best Block	Mean	Range	Best Block
Apr. 95 - Jul. 95	3.8 (22)$^{+}$	0.4-15.2	1.1	18.7 (22)$^{+}$	1.6-106.3	4.3
Aug. 95 - Nov. 95	3.3 (26)	0.3-15.2	1.1	26.0 (26)	1.8-121.5	16.1
Dec. 95 - Mar. 96	3.2 (27)	0.3-15.2	1.1	15.9 (27)	2.3-75.9	9.7
Apr. 96 - Jul. 96	3.1 (27)	0.3-15.2	1.1	17.4 (27)	1.5-62.8	9.7
Aug. 96 - Nov. 96	1.8 (12)	0.4-8.4	-	6.5 (11)	1.1-33.6	-

$^{+}$ Number of blocks with available data indicated in brackets

Cane and sugar yields in the Ord were extremely high during the 1996 harvest season compared with cane growing areas in Queensland (Table 5.5). Since the Ord sugar industry is in its early developmental stages, all of the blocks monitored for this survey were plant cane with a comparatively long crop duration (mean crop age 447 days). There was no clear relationship between sugar yield and harvest date or crop age. Crops of greater age did not necessarily produce higher sugar yields. A yield plateauing phenomenon has been observed in high yielding, long duration crops in Queensland (Muchow et al, 1995). Such a phenomenon may also be occurring in these high yielding Ord crops. Growth analysis studies to quantify yield accumulation over time are therefore required to assess the best crop age for harvest. They will also help explain why current crops appear not to be reaching their yield potential, as predicted using the APSIM model (estimated sugar yields 30.9 tonnes sugar/hectare for a 12 month ratoon crop, Muchow *et al.,* 1996).

Table 5.5. Productivity measures. Results from a survey of 12 growers and 26 blocks.

Measure	Mean	Range	Value for block with highest sugar yield
Cane yield (t ha^{-1})	183	117 - 210	209
Pol % cane *	13.6	10.8 - 16.0	14.3
CCS *	12.4	9.4 -15.0	13.2
Sugar yield (t ha^{-1}) *	22.9	16.8 - 27.5	27.5
Crop age (d)	447	305 - 576	443
Block area (ha)	16.8	2.5 - 45.0	36.3
Harvest date	-	13/06/96 - 10/12/96	25/07/96

* Data only available from 11 growers and 24 blocks

Values of pol % cane and ccs from the 1996 harvest season were lower than anticipated and this has proved to be a major issue affecting the profitability of the Ord Sugar Industry. Whilst drying off before harvest is used to maximise sucrose content, the survey data show no clear relationship between ccs and duration of drying off (Figure 5.3). These data are confounded with different climatic conditions during the period of drying off before the different harvest dates. Since drying-off is an important management strategy available for sugarcane growers in the Ord, there is a need to collect data on crop performance with drying off at different times during the harvest season, so that the findings on drying-off from Queensland projects can be compared with the Ord.

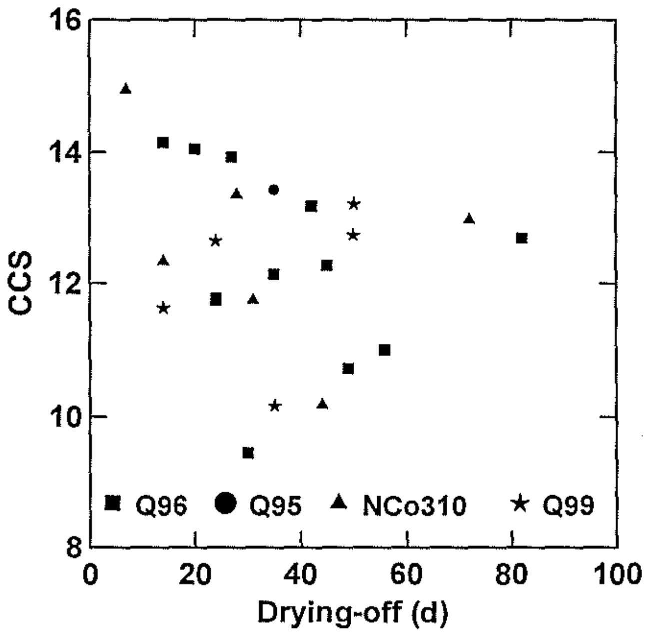


Figure 5.3. Variation in ccs with different durations of drying off before harvest.

Conclusions

The benchmarking survey of irrigation practices confirmed that "best practice" irrigation management had not been developed for sugarcane crops and that many of the growers were applying large amounts of irrigation water at frequent and reasonably uniform intervals throughout the year. The results indicated a number of key information needs:

1. Better estimates of application efficiency and components of the soil water balance.
2. Better definition of water requirements in relation to crop growth and appropriate irrigation schedules that maximise profitability for different crop start and harvest dates.
3. Climate-Crop-Soil-Management data from field experiments and crop logs that can be used to validate simulation models for testing hypotheses and developing options for best practice irrigation.
4. Better information on crop management and the drying-off requirement to maximise sugar content (pol, ccs) and sugar yield for different harvest times throughout the year.

6. DRYING OFF EXPERIMENTS

Introduction

In irrigated sugarcane production, water is commonly withheld prior to harvest in order to dry out the field and make it suitable for mechanical harvesting operations. In the Burdekin area this practice also increases both the sucrose concentration of the cane as well as the sucrose yield (Robertson *et al.*, 1999a; Robertson *et al.*, 1999b). The optimum length of the drying off period depends on the rate of development of the crop water deficit and the associated changes in sucrose yield, cane yield and sucrose concentration. The imposition of a water deficit through drying off commonly reduces stalk yield through reduced carbon assimilation but leads to an increase in sucrose concentration through increased partitioning of dry matter within the plant towards sucrose. Generally drying off is more often associated with an increase in sucrose concentration rather than with a reduction in cane yield (Robertson and Donaldson, 1998).

In the early irrigation experiments with sugarcane in the Ord, little or no response in sucrose yield was obtained to drying off (Kingston *et al.*, 1980; Gallagher, 1986). It was concluded that a 3-5 week drying off period was adequate for most of the harvest season and that if the drying off period exceeded 6-8 weeks then the cane tends to deteriorate with losses of both cane yield and sucrose concentration (Bureau of Sugar Experiment Stations, 1982). It was decided to test these guidelines by conducting a series of field trials to quantify the impact of different drying off strategies on cane yield and sucrose concentration.

Drying off experiments

Seven field drying off experiments were conducted during the period 1996-1998 (Table 6.1).

Table 6.1. Drying off experiments conducted in the Ord.

Block No/ Plot size	Variety/ Crop Class	Crop Start Date	Harvest Date	Drying-off Treatment (days)	Cane Yield (t ha^{-1})	Adjusted Pol	Pol Yield (t ha^{-1})
230.3.10 1.24 ha	Q99 1R	02/05/96	18/09/97	42	143	13.6	19.3
				72	138	13.6	18.7
				82	144	13.6	19.5
300.11.20 1.81 ha	Q99 1R	01/08/96	17/08/97	48	147	14.5	21.3
				62	143	14.2	20.3
				74	145	14.2	20.6
220.21.10 2.43 ha	Q95 1R	20/09/96	29/08/97	20	131	15.5	20.4
				30	127	16.4	20.9
				43	135	15.9	21.6
230.3.10 1.24 ha	Q99 2R	18/09/97	29/10/98	20	159	11.4	18.2
				37	147	12.0	16.9
				37	154	12.2	18.8
300.11.20 1.81 ha	Q99 2R	17/08/97	22/07/98	38	149	14.0	20.8
				52	155	13.4	20.8
				66	148	13.4	19.9
220.21.10 2.43 ha	Q95 2R	29/08/97	2/10/98	40	147	15.2	22.6
				54	146	15.1	22.0
				68	143	15.7	22.4
FWI 3B 0.778 ha	Q99 P	13/05/97	7/07/98	24	193	10.6	21.1
				47	184	10.6	19.5
				80	180	10.5	19.0

Six of the experiments were located on commercial fields with the crops being grown using the commercial practices of individual growers. The other experiment was located on Block 3B at the Frank Wise Institute Research Station. Blocks were selected with a minimum of 200 drills to allow the different drying off treatments to be spaced out so that lateral soakage would not be a problem between treatments. Each treatment occupied at least 10 drills so that the rakes would be weighed and analysed separately at the mill and each drying off treatment was replicated three times.

The response to drying off prior to harvest was examined by withholding irrigations for varying times prior to harvest. The drying off treatments were chosen by the growers in consultation with the research team. Each grower was responsible for applying the treatments and for completing a crop log which detailed the crop management activities on the particular trial block. The cane in each replicate was mechanically harvested and both cane yield and Pol were determined at the Ord sugar mill. In addition, for the four experiments conducted in 1997-1998, treatments were sampled by hand at least twice before the drying off treatments were imposed and again at final harvest. Total fresh weight, millable stalk fresh weight and dry matter content were recorded at each sampling and a stalk count was conducted. Also juice samples were obtained after fibrating and processing the samples through a Carver Press for determination of brix, pol and fibre. No rainfall was recorded during the drying off periods.

Results

1996-97 experiments

In the 3 experiments conducted during 1996-97, the drying off periods ranged from 3-7 weeks, 4-10 weeks and 6-12 weeks. Results of cane yield, adjusted Pol and Pol yield by commercial harvesting are given in Table 6.1. Statistical analysis showed that there were no significant effects of drying off on either cane yield, Pol or Pol yield, which is surprising given the extended drying off periods of up to 82 days. Both cane yields and adjusted Pol readings were remarkably consistent across treatments.

1997-98 experiments

The experiments were repeated on the same blocks as in 1996-97, although the drying off periods were different. Again the cane yield and Pol readings obtained from the 3 commercial farms were very similar between treatment and showed no significant differences. An additional drying off trial was conducted in plant cane in Block 3B at the Frank Wise Institute research farm. The results in this trial did show reduced cane yields with increasing drying off periods, although there was no difference in adjusted Pol between treatments, even though the cane harvested from the 80 day drying off period appeared severely dessicated with virtually no green leaves.

Results of the hand-samplings conducted on the four trials in 1997-98 are given in Figures 6.1-6.4. In only one trial, Block 3B at the Frank Wise Research Institute, were there any significant differences between treatments (Table 6.2). In this trial, the 80 day drying off treatment had a significantly lower CCS, Pol % cane, Pol yield, purity, and on a dry weight basis a significantly lower stalk sucrose concentration and significantly higher stalk fibre concentration and stalk nitrogen concentration. Most of these, however, were not significant for the 47 day treatment.

Table 6.2. Results of drying off experiment conducted at Block 3B, Frank Wise Institute. Sample 6 (6/7/98), 419 days after planting. (* $P<0.05$, ** $P<0.01$, *** $P<0.001$)

Variate	Q96 P 24 days dry-off	Q96 P 47 days dry off	Q96 P 80 days dry-off
Cane yield (t ha^{-1})	156	152	144
Stalk number (m^{-2})	6.4	6.7	6.5
CCS **	9.0	8.7	6.6
Pol % cane *	10.8	10.6	9.2
Pol yield (t ha^{-1}) **	16.9	16.1	13.2
Brix % cane	14.7	14.8	14.4
Purity (%) **	73.7	71.9	63.8
Stalk sucrose concentration (g g^{-1} FW)	0.115	0.116	0.0990
Stalk sucrose yield (t ha^{-1}) *	18.0	17.5	14.3
Stalk sucrose concentration (g g^{-1} DW) *	0.422	0.418	0.368
Stalk fibre concentration (g g^{-1} FW)	0.132	0.140	0.136
Stalk fibre (t ha^{-1})	20.6	21.1	19.6
Stalk fibre concentration (g g^{-1} DW) *	0.484	0.502	0.506
Stalk dry matter content (g DW g^{-1} FW)	0.272	0.278	0.269
Stalk biomass (t ha^{-1})	42.5	42.1	38.8
Stalk N (kg ha^{-1})	91.5	109	122
Stalk N concentration (mg N g^{-1} DW) *	2.15	2.58	3.17
Commercial Harvest:			
Cane yield (t ha^{-1})	193	184	181
Adjusted Pol	10.6	10.6	10.5

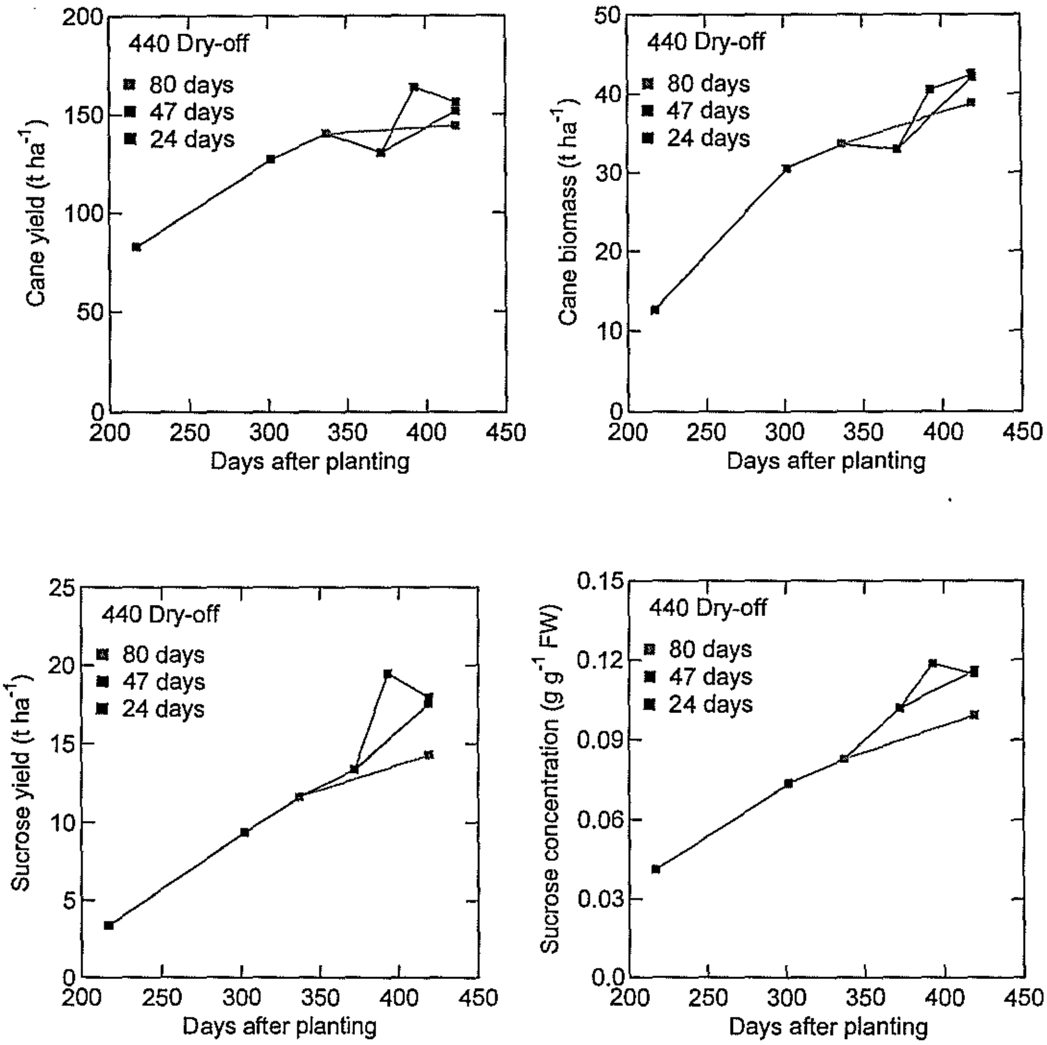


Figure 6.1. Effect of three drying off treatments on cane yield (t ha^{-1}), cane biomass (t ha^{-1}), sucrose yield (t ha^{-1}) and fresh weight sucrose concentration (g g^{-1}) in the drying off trial conducted in Block 3B at the Frank Wise Research Institute (trial # 440). (Sucrose yield and sucrose concentration were significantly different ($p<0.01$) for the 80 day dry-off treatment at 419 days after planting).

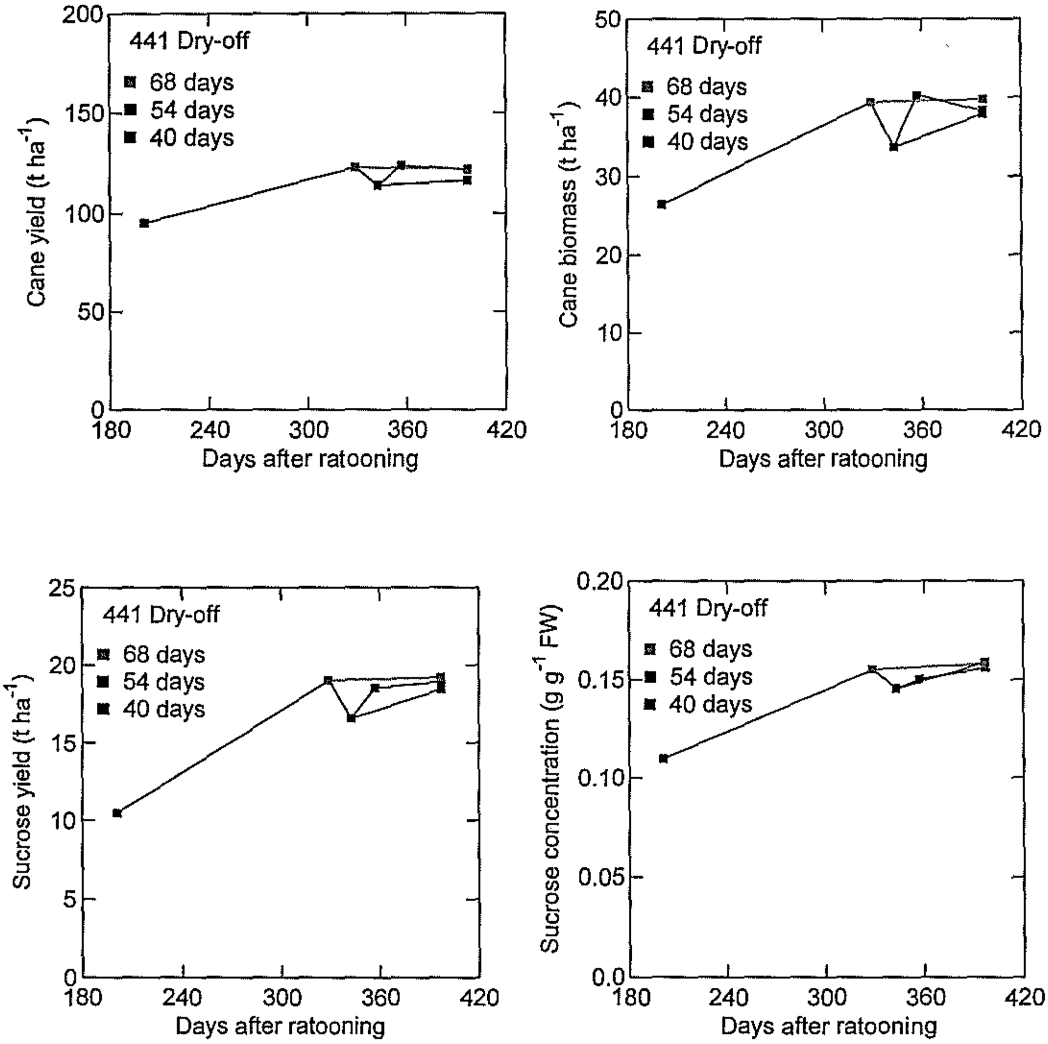


Figure 6.2. Effect of three drying off treatments on cane yield (t ha^{-1}), cane biomass (t ha^{-1}), sucrose yield (t ha^{-1}) and fresh weight sucrose concentration (g g^{-1}) in the drying off trial conducted in Block 220.21.10 at Oasis Farms (trial # 441).

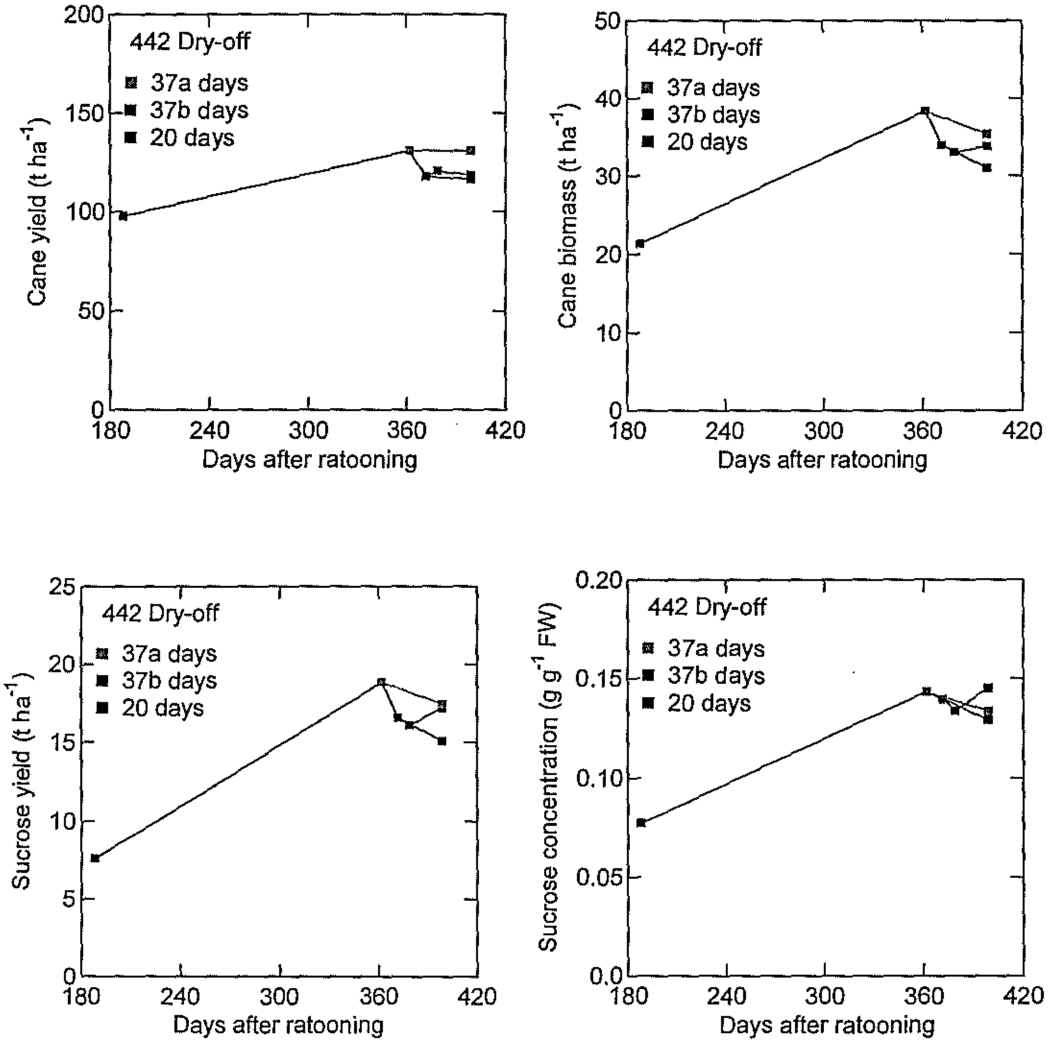


Figure 6.3. Effect of three drying off treatments on cane yield (t ha^{-1}), cane biomass (t ha^{-1}), sucrose yield (t ha^{-1}) and fresh weight sucrose concentration (g g^{-1}) in the drying off trial conducted in Block 230.3.10 at Pegg's farm (trial # 442).

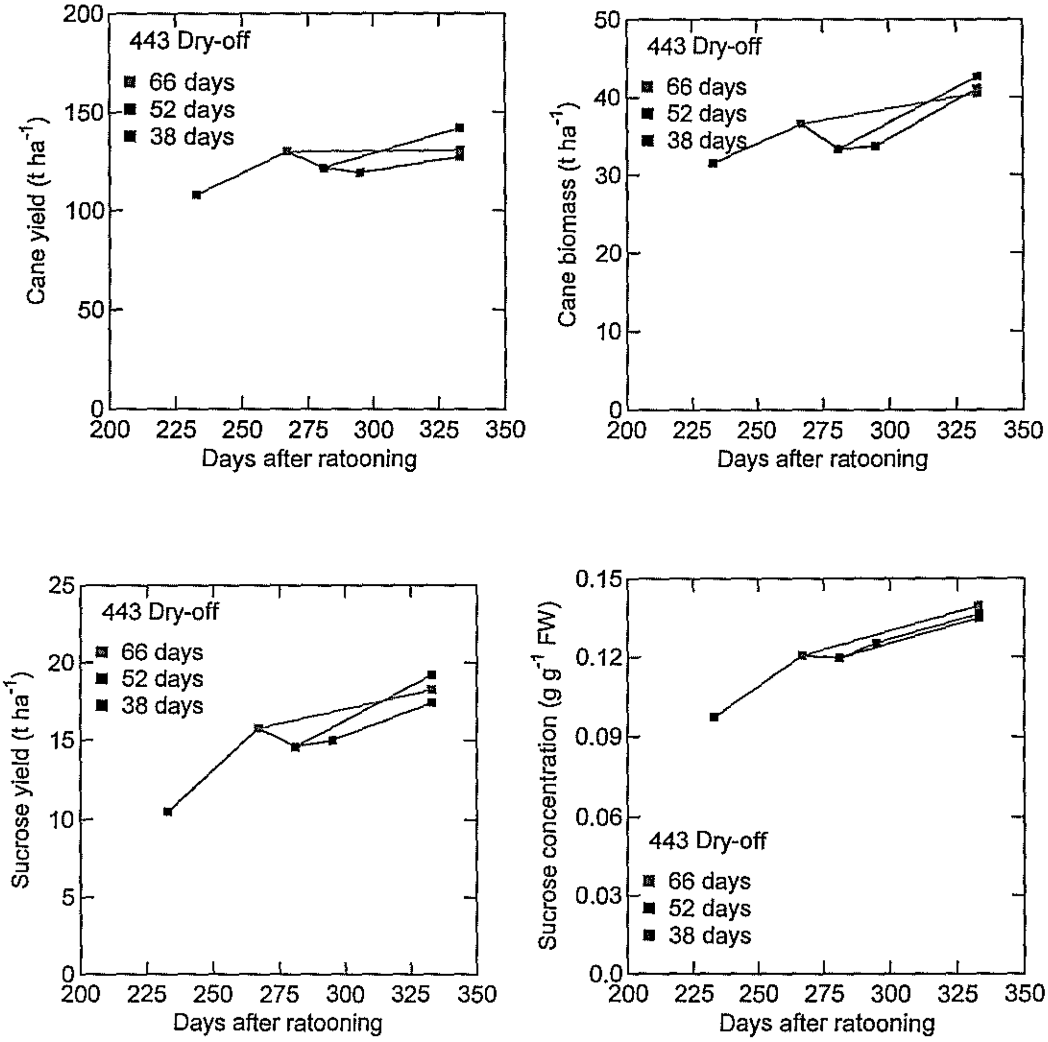


Figure 6.4. Effect of three drying off treatments on cane yield (t ha^{-1}), cane biomass (t ha^{-1}), sucrose yield (t ha^{-1}) and fresh weight sucrose concentration (g g^{-1}) in the drying off trial conducted in Block 300.11.20 at Cummings Brothers' farm (trial # 443).

Discussion

Robertson and Donaldson (1998) reviewed many drying off trials conducted in South Africa and Australia. They showed that the likelihood of a response to drying off is highly variable. The absence of a response to drying off in terms of sucrose concentration or stalk dry matter content in these trials could be associated with sugarcane crops in the Ord being capable of extracting large amounts of water from the soil profile. It may also be related to low rates of crop water use. The data presented in Figures 6.1-6.4 suggest that cane growth, and consequently crop water use, was generally quite slow when the drying off treatments were imposed. Consequently the drying off treatments were not able to impose much stress on the growth of the crop or initiate an increase in sucrose accumulation. This issue will be further discussed in the next chapter.

It therefore appears likely that drying off cannot be used as a strategy for increasing cane sucrose content in the Ord unless the cane is still growing rapidly when drying off commences. Where cane growth has already slowed down, the main advantage of drying off will be to dry the soil surface, induce cracking in the soil and improve trafficability. Given the findings of these 7 trials, it is recommended that the drying off strategy should be tailored to allow fields to be dried out sufficiently for mechanical harvesting. Extending the drying off period would promote cracking and would benefit soil structure (P. McCosker, pers. comm.) and would also result in labour and water savings associated with less irrigation. However the results from the experiment at Block 3B at the Frank Wise Research Institute indicate that it is possible to dry off for too long. The 80 day dry down treatment resulted in a significant reduction in CCS and purity.

7. IRRIGATION SCHEDULING TRIALS

Introduction

In section 1 it was noted that much of the early irrigation scheduling work with sugarcane in the ORIA was inconclusive with little or no response to irrigation frequency. Consequently when commercial sugar production began in the Ord, irrigation schedules of 25-30 irrigations per crop year were adopted. Watering the crop every 10-14 days throughout the year was regarded as being necessary because sugarcane crops growing in the unique climatic conditions of the Ord had an extremely high water requirement. To quantify the yield responses to different irrigation schedules a field experimental programme was conducted so that improved irrigation practices could be developed which not only maximised sugar yields and profitability but also improved the efficiency of irrigation water use and led to a stabilisation of rising water tables.

Choice of treatments

The irrigation scheduling trial was established in 1998. Treatments imposed at canopy closure in the first year were 60, 120 and 180 mm of cumulative daily evaporation (Class A Pan). Treatments were imposed throughout the season until dry down, five weeks prior to harvest in July 1999. After analysis of the data and consideration of the results it was decided that the treatments in the second year of the trial should be based on soil moisture deficit. The quantity of water available to sugarcane over a depth of 1.9 metres was calculated to be 225mm. Irrigation was scheduled after the sugarcane had removed of 79, 123 and 191 mm of the available water. Irrigation prior to canopy closure was scheduled at 120mm cumulative evaporation for both crops.

Growth analysis data

Plant crop experiment

Stalk population declined in all treatments up to about 300 days after planting and then remained at about 8 stalks per m^2 (Figure 7.1). Stalk population often decreases slowly at this stage due to lodging or water stress but there was no sign of these stresses in this experiment in regard to stalk population at least.

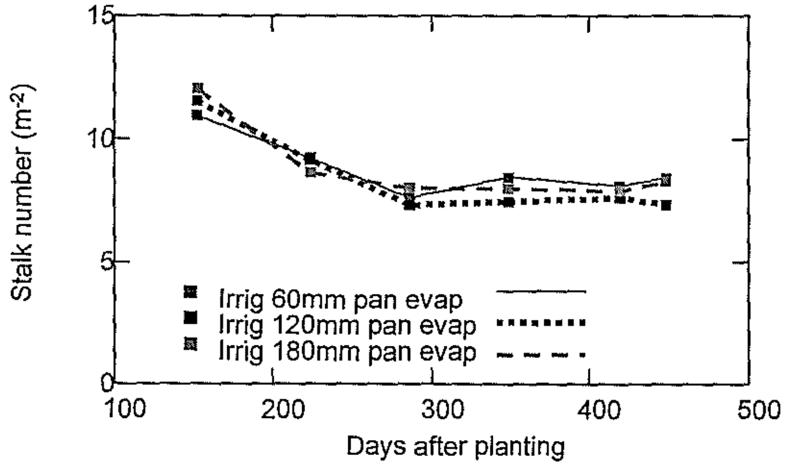


Figure 7.1. Stalk population for three irrigation scheduling treatments applied to a plant crop Q99 in the Ord (1998/1999)

Green leaf area index (LAI) was as high as 6.0 in the most frequent irrigation regime (60 mm pan evaporation). LAI decreased over time (Figure 7.2) due to declining stalk population and declining leaf area per stalk (Figure 7.3). LAI stabilized after 300 days (Fig 7.2). The only indication that the water was limiting in the 180 mm treatment was the reduced LAI in this treatment at the time of the second sampling.

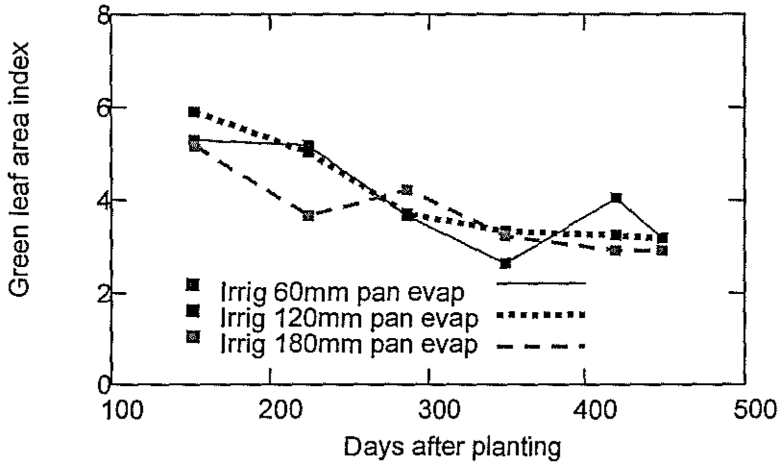


Figure 7.2. Green leaf area index for three irrigation scheduling treatments applied to a plant crop Q99 in the Ord (1998/1999)

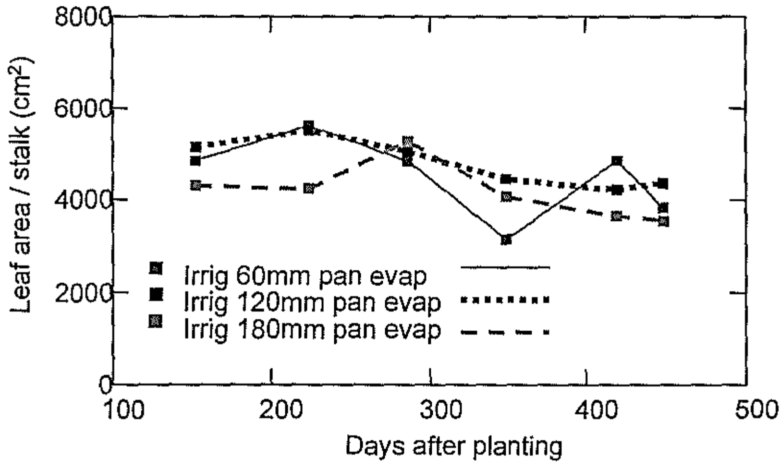


Figure 7.3. Leaf area per stalk for three irrigation scheduling treatments applied to a plant crop Q99 in the Ord (1998/1999)

Cane biomass (or stalk dry matter yield) increased rapidly in all treatments but was reduced significantly by lack of irrigation at the time of the 2nd and 4th samplings (Figure 7.4, Table 7.1). Had the crop been harvested at 12 months cane biomass yield would have been reduced significantly by allowing 180 mm pan evaporation to accumulate rather than irrigating more frequently at 120 or 60 mm deficit. However the crop was harvested at 15 months even though there was little further yield accumulation in cane stalks. At harvest there was no difference between treatments in regard to cane biomass yield.

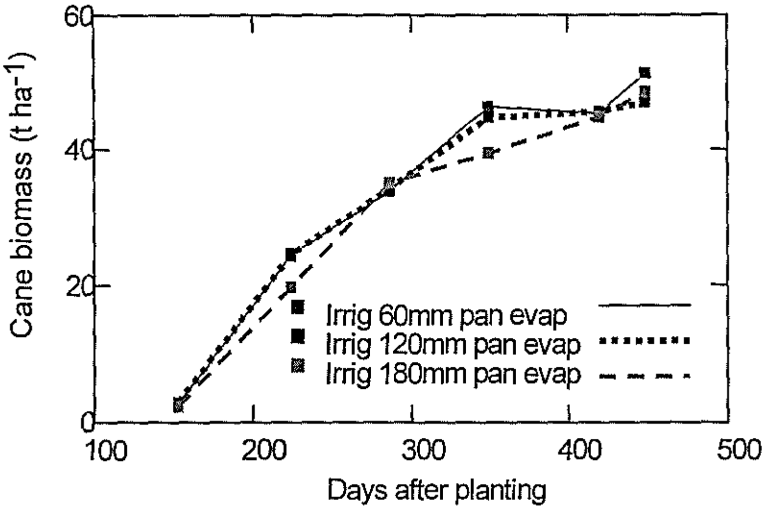


Figure 7.4. Cane biomass (stalk dry mass) for three irrigation scheduling treatments applied to a plant crop Q99 in the Ord (1998/1999)

Accumulation of cane biomass was due more to increased dry matter concentration (Figure 7.5) than to increased cane yield (Figure 7.6). Stalk dry matter content increased by 68% during the growth analysis period compared to an increase of only 25 % for cane yield. The greatest increase in cane yield was for the 180 mm pan treatment. Cane yield for this treatment was lower than the other treatments in December 1998. No other differences in cane yield were significant so yield of the driest treatment can be said to have 'caught up' with the more generously irrigated treatments during the wet season. However cane yield determined by mechanically harvesting was in fact significantly reduced by withholding irrigation until 180 mm pan evaporation had accumulated (Table 7.2). It is remarkable that a mean cane yield of 142 t/ha was measured 224 days after planting and after another 225 days, yield increased by only a further 36 t/ha.

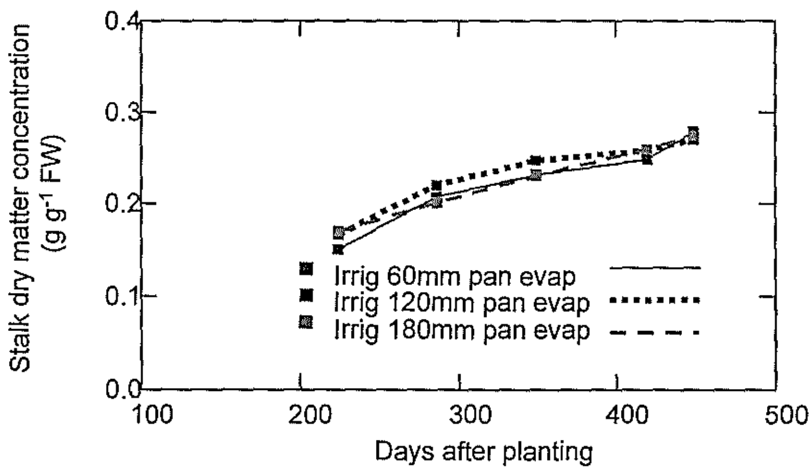


Figure 7.5. Stalk dry matter content for three irrigation scheduling treatments applied to a plant crop Q99 in the Ord (1998/1999)

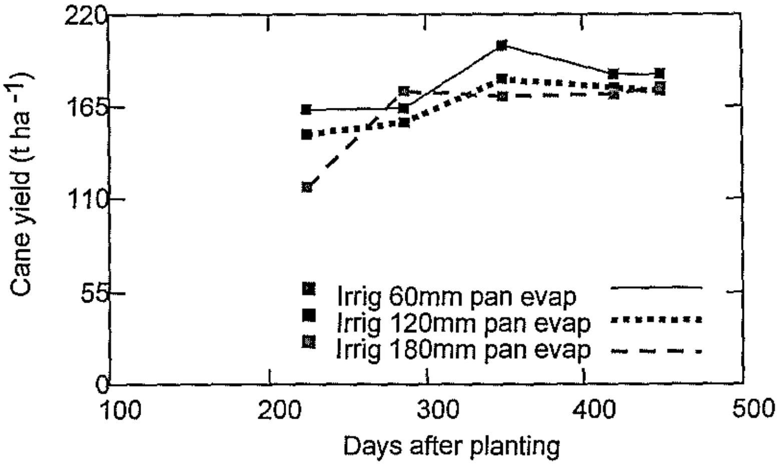


Figure 7.6. Cane yield for three irrigation scheduling treatments applied to a plant crop Q99 in the Ord (1998/1999)

Sucrose concentration on a dry (Figure 7.7) and a fresh weight basis (Figure 7.8) decreased significantly with increased irrigation prior to the wet season. The crops in the 120 and 180 mm irrigation regimes were therefore under some degree of water stress resulting in a 'ripening' response associated with greater partitioning of photosynthate to sucrose in the stalk than in the 60 mm irrigation regime. In April (349 days) differences in the opposite direction were significant for sucrose content of dry mass (Table 7.1). This demonstrates the dynamic nature of the effect of irrigation regime on sucrose content which can increase initially due to changes in carbohydrate partitioning but can then decrease in stressed plants because of retarded development. Growth retardation will result in shorter stalks with a greater proportion of immature top than in better developed stalks.

Although sucrose content at harvest was not significantly different between treatments (Table 1) it is reasonable to assume that the increase in sucrose content was in fact due to increased irrigation because of the significance of an earlier result and also because of the significant effect of treatment on sucrose yield. .

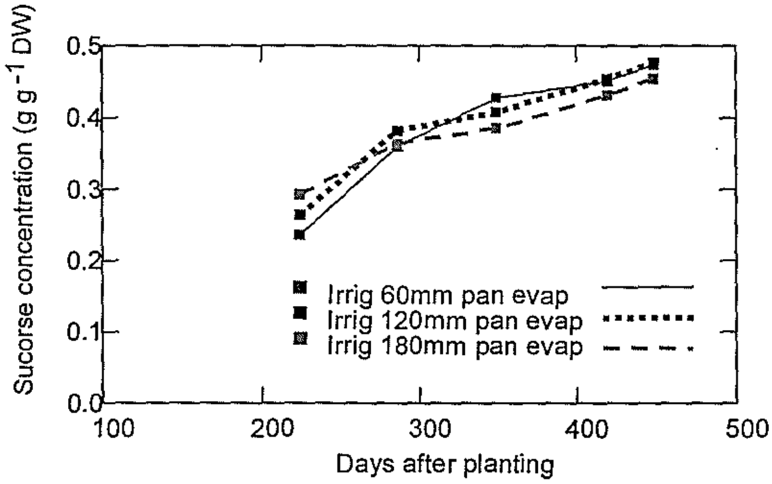


Figure 7.7. Sucrose content on a dry weight basis for three irrigation scheduling treatments applied to a plant crop Q99 in the Ord (1998/1999)

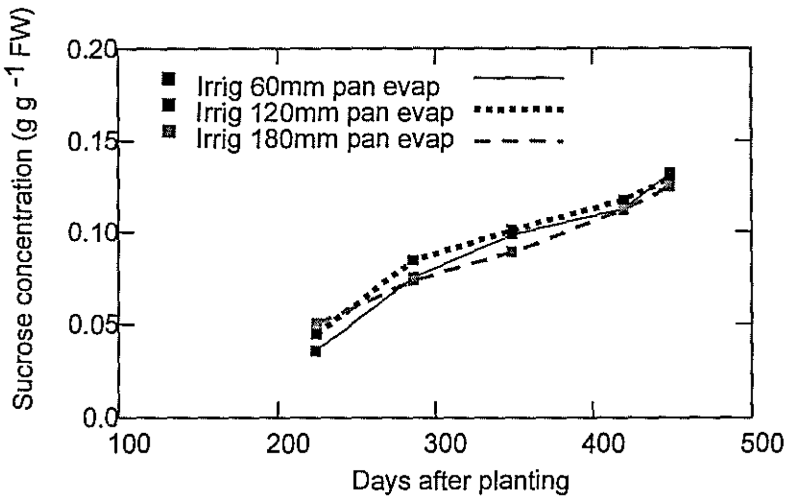


Figure 7.8. Sucrose content on a fresh weight basis for three irrigation scheduling treatments applied to a plant crop Q99 in the Ord (1998/1999)

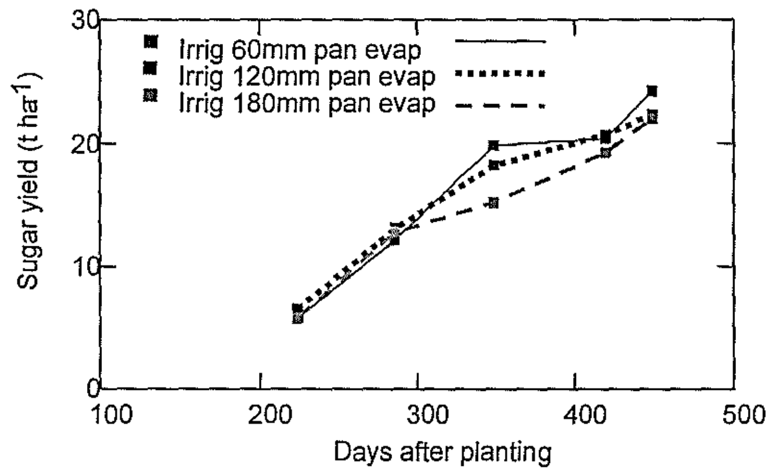


Figure 7.9. Sucrose yield for three irrigation scheduling treatments applied to a plant crop Q99 in the Ord (1998/1999)

Sucrose yield increased significantly with irrigation in April and July (Figure 7.9, Table 7.1). A similar effect was obtained from the yields determined by mechanically harvesting the experimental plots, although the results were not significant (Table 7.2). Given the low cost of water, the most frequent irrigation treatment would probably be justified on the basis of these results. Cost of irrigation is estimated to be about $3 per irrigation per ha. The 60 mm schedule received 9 more irrigations than the 120 mm schedule costing about $27/ha more. A sucrose yield benefit of 1.6 t/ha in April and 1.9 t/ha in July by following the 60 mm rather than the 120 mm pan evaporation schedule would probably be justified when considering on farm costs. However one may ask if the additional yield is really worth the large amount of additional water considering the likely adverse effect on the water table and on the quality of water running off the farm and back into the river system.

Table 7.1. Plant crop results of irrigation scheduling trial (#444) growth analysis, Block 2B, Frank Wise Institute, Q99 Planted 06/05/98. (* p<0.05; ** p<0.01; *** p<0.001)

Variate	Significance	Sampling date	Days after planting	Q99 P 60 mm Pan Evap	Q99 P 120 mm Pan Evap	Q99 P 180 mm Pan Evap	Mean
Brix % cane	*	16/12/1998	224	6.9	7.8	8.4	7.7
		16/02/1999	286	9.7	10.7	9.5	10.0
		20/04/1999	349	11.8	12	11.1	11.6
		30/06/1999	420	12.8	13.4	13.1	13.1
		29/07/1999	449	14.7	14.3	13.9	14.3
Cane yield (t ha-1)	**	16/12/1998	224	163	148	116	142.3
		16/02/1999	286	164	155	174	164.3
		20/04/1999	349	201	181	171	184.3
		30/06/1999	420	184	176	172	177.3
		29/07/1999	449	184	174	177	178.3
CCS	*	16/12/1998	224	1.8	2.7	3.3	2.6
		16/02/1999	286	6.4	7.4	6.4	6.7
		20/04/1999	349	9.1	9.5	8	8.9
		30/06/1999	420	11.2	11.6	10.9	11.2
	*	29/07/1999	449	13.5	12.9	12.5	13.0
Pol % cane	*	16/12/1998	224	3.6	4.4	5	4.3
		16/02/1999	286	7.5	8.4	7.3	7.7
		20/04/1999	349	9.9	10.1	8.9	9.6
		30/06/1999	420	11.3	11.7	11.2	11.4
		29/07/1999	449	13.4	12.9	12.4	12.9
Pol yield (t ha-1)		16/12/1998	224	5.7	6.5	5.8	6.0
		16/02/1999	286	12.1	13.1	12.8	12.7
	*	20/04/1999	349	19.8	18.2	15.2	17.7
		30/06/1999	420	20.4	20.7	19.3	20.1
	*	29/07/1999	449	24.6	22.4	22	23.0
Purity (%)	*	16/12/1998	224	51.2	56.7	59.5	55.8
		16/02/1999	286	76.7	78.9	76.9	77.5
		20/04/1999	349	83.2	83.9	79.7	82.3
		30/06/1999	420	87.3	87.5	85.7	86.8
	**	29/07/1999	449	91.1	90	89.7	90.3
Stalk biomass (t ha-1)	*	16/12/1998	224	24.4	24.6	19.8	22.9
		16/02/1999	286	33.9	34.1	35.1	34.4
	*	20/04/1999	349	46.3	44.6	39.3	43.4
		30/06/1999	420	45.2	45.5	44.8	45.2
		29/07/1999	449	51.3	46.9	48.4	48.9
Stalk dry matter content (g DW g-1 FW)	*	16/12/1998	224	0.15	0.167	0.17	0.162
		16/02/1999	286	0.207	0.22	0.201	0.209
		20/04/1999	349	0.231	0.247	0.23	0.236
		30/06/1999	420	0.248	0.258	0.259	0.255
		29/07/1999	449	0.279	0.27	0.274	0.274
Stalk fibre (t ha-1)	**	16/12/1998	224	16.4	15.6	11.6	14.5
		16/02/1999	286	18.6	18.9	19.4	19.0
		20/04/1999	349	23.6	23.6	21	22.7
		30/06/1999	420	23	22.2	23.4	22.9
		29/07/1999	449	25	23.1	25.3	24.5
Stalk fibre concentration (g g-1 DW)	*	16/12/1998	224	0.673	0.634	0.588	0.632
		16/02/1999	286	0.548	0.553	0.554	0.552
		20/04/1999	349	0.509	0.528	0.533	0.523

		30/06/1999	420	0.508	0.488	0.524	0.507
		29/07/1999	449	0.487	0.492	0.523	0.501
Stalk fibre concentration (g g-1 FW)		16/12/1998	224	0.101	0.105	0.1	0.102
		16/02/1999	286	0.114	0.122	0.111	0.116
		20/04/1999	349	0.118	0.13	0.123	0.124
		30/06/1999	420	0.126	0.126	0.136	0.129
		29/07/1999	449	0.136	0.133	0.143	0.137
Stalk N (kg ha-1)		20/04/1999	349	160	152	160	157
Stalk N conc. (mg N g-1 DW)		20/04/1999	349	3.4	3.4	4.07	3.6
Stalk number (m-2)		16/12/1998	224	9.2	9.1	8.6	9.0
		16/02/1999	286	7.6	7.3	8	7.6
		20/04/1999	349	8.4	7.5	7.9	7.9
		30/06/1999	420	8.1	7.6	7.9	7.9
		29/07/1999	449	8.4	7.3	8.3	8.0
Stalk sucrose concentration (g g-1 DW)	*	16/12/1998	224	0.236	0.264	0.293	0.264
		16/02/1999	286	0.36	0.382	0.364	0.369
	*	20/04/1999	349	0.427	0.408	0.385	0.407
		30/06/1999	420	0.451	0.454	0.431	0.445
		29/07/1999	449	0.474	0.477	0.455	0.469
Stalk sucrose concentration (g g-1 FW)	*	16/12/1998	224	0.0356	0.0443	0.0498	0.043
		16/02/1999	286	0.0747	0.0841	0.0732	0.077
		20/04/1999	349	0.0985	0.1008	0.0885	0.096
		30/06/1999	420	0.113	0.117	0.112	0.114
		29/07/1999	449	0.132	0.129	0.124	0.128
Stalk sucrose yield (t ha-1)		16/12/1998	224	5.74	6.5	5.79	6.0
		16/02/1999	286	12.1	13.1	12.8	12.7
	*	20/04/1999	349	19.8	18.2	15.2	17.7
		30/06/1999	420	20.4	20.7	19.3	20.1
	**	29/07/1999	449	24.2	22.3	22	22.8

Table 7.2. Commercial yields of crops harvested on 4/8/99 and grown under different irrigation schedules based on cumulative Class A pan evaporation. All crops were irrigated after 120 mm pan evaporation prior to canopy closure and irrigation was terminated 33 days prior to harvest for drying-off. Statistical analysis showed only cane yield to be significant at p=0.05.

Variate	Q99 P Irrig 60mm Pan Evap	Q99 P Irrig 120 mm Pan Evap	Q99 P Irrig 180 mm Pan Evap
Cane yield (t ha^{-1}) **	218	212	195
Unadjusted Pol	11.3	11.1	11.9
Adjusted Pol (+1.1)	12.4	12.2	13.0
Pol yield (t ha^{-1}) using adjusted pol	27.0	25.9	25.4

First ratoon experiment

Stalk population declined rapidly between January and April (99 days to 160 days after ratooning) probably due to the loss of small tillers that were shaded out when the canopy closed fully. A further mean loss of 1.5 stalks/m^2 was encountered between April and

September (Figure 7.10, Table 7.3). These were probably larger stalks that would have contributed significantly to accumulated biomass. Although such losses need to avoided if possible, there was no indication that irrigation had anything to do with stalk loss at this time. Leaf area index rose to nearly 6 after the wet season, this time in the driest irrigation treatment. LAI then decreased considerably in all treatments but more so in the driest treatment (191 mm deficit). LAI for this treatment was less than 1.0 at harvest which is indicative of fairly severe water stress (Figure 7.11). LAI and area per stalk did not differ much between the 79 and 123 mm deficit treatments (Figure 7.10, 7.11).

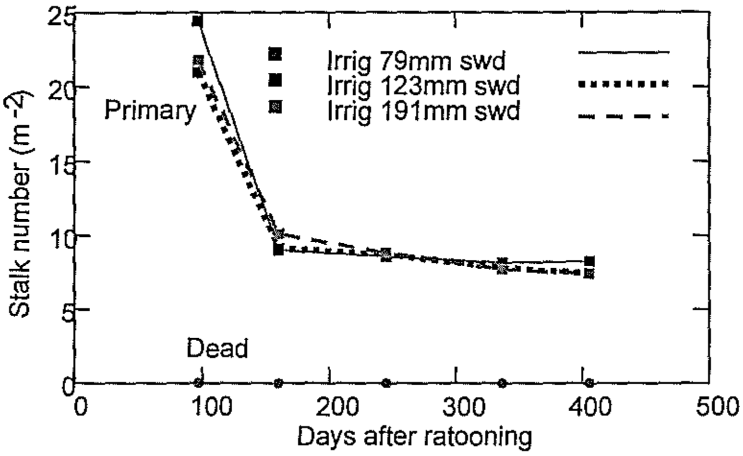


Figure 7.10. Stalk population for three irrigation scheduling treatments applied to a first ratoon crop Q99 in the Ord (1999/2000)

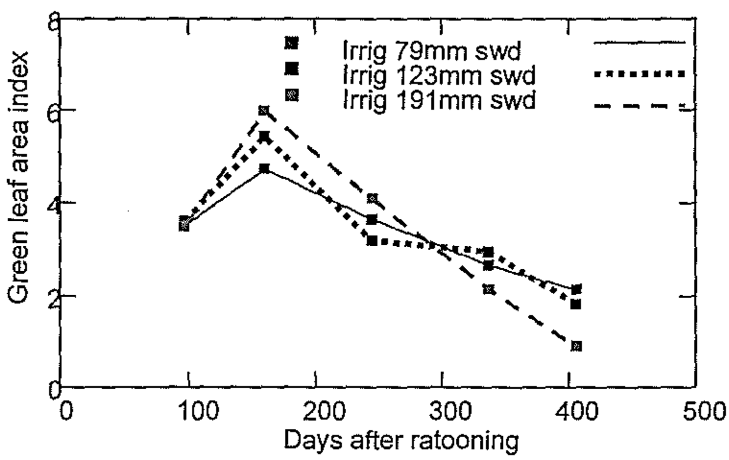


Figure 7.11. Green leaf area index for three irrigation scheduling treatments applied to a first ratoon crop Q99 in the Ord (1999/2000)

Cane biomass increased rapidly up to 245 days after ratooning and then more gradually with very little growth observed between 337 and 406 days after ratooning. Cane biomass accumulation in the 191 mm treatment practically ceased after 245 days (Figure 7.12) but treatment differences were not significantly different at any stage (Table 3). As was the case in the plant crop, cane biomass accumulation was associated with increasing dry matter content (Figure 7.13) more than with an increased cane yield (Figure 7.14). Yields exceeding

100 t cane/ha were measured after only 245 days of growth but more than 90% of this material was water. Mean cane yield increased only to 133 t/ha, 337 days after ratooning. Irrigation treatment had no significant effect on cane yield. The lack of response to irrigation and the low yield raises the question about factors other than water that may have been limiting yield.

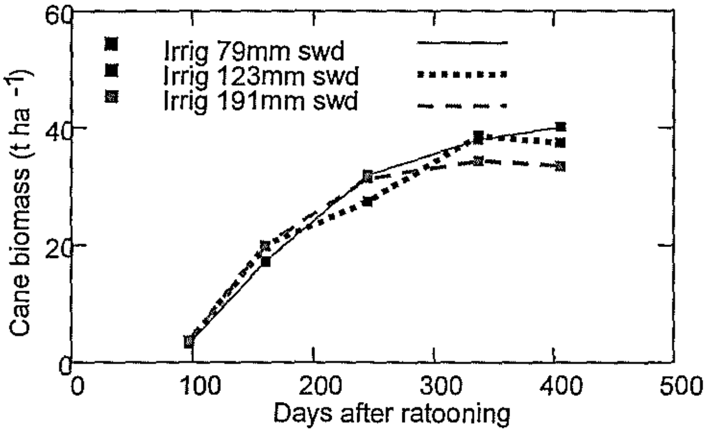


Figure 7.12. Cane biomass for three irrigation scheduling treatments applied to a first ratoon crop Q99 in the Ord (1999/2000)

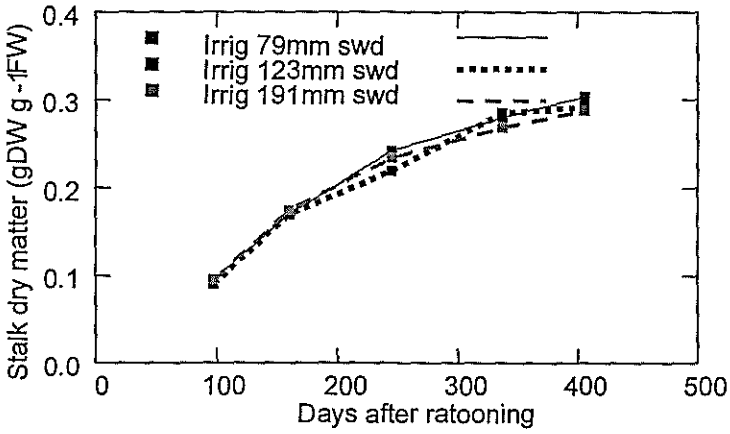


Figure 7.13. Stalk dry matter content for three irrigation scheduling treatments applied to a first ratoon crop Q99 in the Ord (1999/2000)

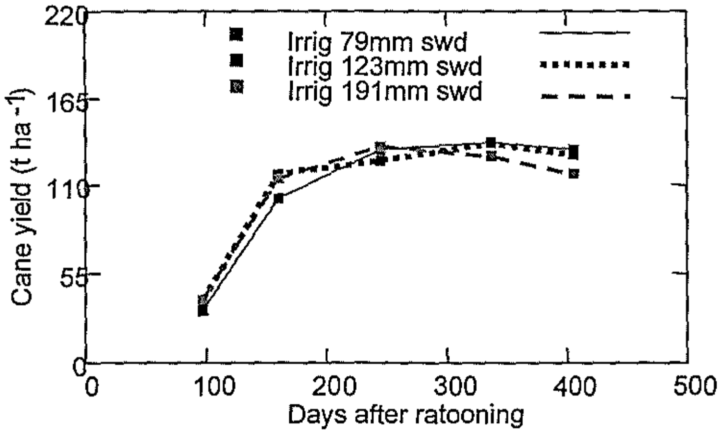


Figure 7.14. Cane yield for three irrigation scheduling treatments applied to a first ratoon crop Q99 in the Ord (1999/2000)

Sucrose content on both a dry and fresh weight basis, reached slightly higher values than in the plant crop, but sucrose content in this experiment was nowhere near the maximum values often obtained in Queensland (0.55 and 0.18 on dry and fresh mass bases respectively). Sucrose content for the 191 mm treatment decreased between 337 and 406 days after ratooning (Figures 7.15 and 7.16) and the treatment effect on both expressions of sucrose content was significant at harvest. Juice purity in this treatment also decreased before harvest probably because water stress was severe enough to lead to senescence in some stalks (Table 7.3).

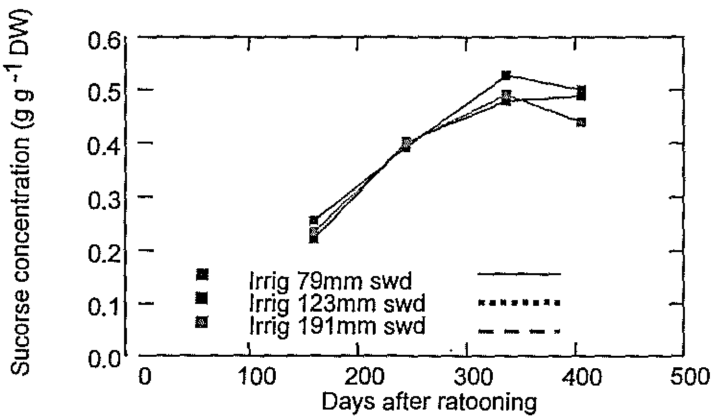


Figure 7.15. Sucrose content on a dry matter basis for three irrigation scheduling treatments applied to a first ratoon crop Q99 in the Ord (1999/2000)

Sucrose yield in July (337 days) and September (406 days) was reduced significantly by the less frequent irrigations compared to frequent irrigations applied when soil water deficit was 79 mm (Figure 7.17). There was a penalty of 1.3 t sucrose /ha in July and 1.6 t sucrose/ha in September by scheduling irrigation at a 123 m deficit rather than a 79 mm deficit. However eight irrigations were saved whilst incurring this small yield loss. This result is similar to that obtained in the plant crop experiment where it was concluded that the irrigations saved may not be economically justified by a sucrose yield penalty of about 1.5 t/ha. Sucrose yield loss in the 191 mm treatment was 3.0 and 5.3 t/ha respectively in July and September. Irrigating at this large deficit saved 11 irrigations, three more than the 123 mm treatment but the yield loss was disproportionate to the water saved. The choice of the 123 mm deficit irrigation schedule would be a good compromise between water savings and yield loss.

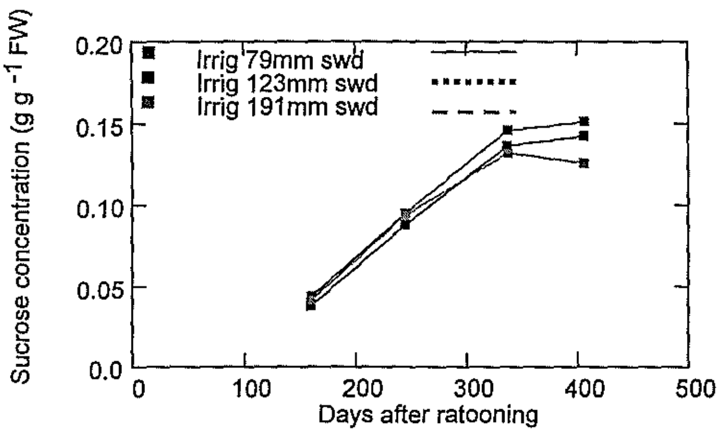


Figure 7.16. Sucrose content on a fresh weight basis for three irrigation scheduling treatments applied to a first ratoon crop Q99 in the Ord (1999/2000)

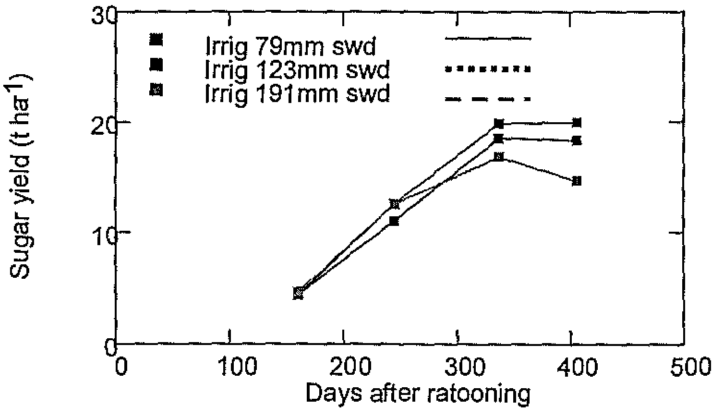


Figure 7.17. Sucrose yield for three irrigation scheduling treatments applied to a first ratoon crop Q99 in the Ord (1999/2000)

Yields obtained from mechanically harvesting these plots were slightly different to the yields obtained by hand sampling (Table 7.4). The 123 mm treatment gave the highest commercial cane and sucrose yield (Table 7.4) and the 191 mm treatment gave the lowest yields. However none of these differences were statistically significant.

Table 7.3. First ratoon results of irrigation scheduling trial (#445) growth analysis, Block 2B, Frank Wise Institute, Q99 1R Ratooned 04/08/99 * p<0.05; ** p<0.01; *** p<0.001

Variate	Significance	Sampling date	Days after ratooning	Q99 1R 79 mm Soil Water Deficit	Q99 1R 123 mm Soil Water Deficit	Q99 1R 191 mm Soil Water Deficit
Brix % cane		11/01/2000	160	7.6	7.6	7.7
		5/04/2000	245	11.3	10.8	11.2
		6/07/2000	337	15.6	14.9	14.4
		13/09/2000	406	16	15.3	14.7
Cane yield (t ha-1)		11/01/2000	160	101	117	114
		5/04/2000	245	132	125	134
		6/07/2000	337	136	136	128
		13/09/2000	406	132	129	117
CCS		11/01/2000	160	2.7	1.8	2.3
		5/04/2000	245	8.8	8	8.6
		6/07/2000	337	14.8	13.7	13.1
	***	13/09/2000	406	15.6	14.6	12.2
Pol % cane		11/01/2000	160	4.3	3.8	4.1
		5/04/2000	245	9.5	8.8	9.3
		6/07/2000	337	14.6	13.6	13.1
	**	13/09/2000	406	15.1	14.2	12.5
Pol yield (t ha-1)		11/01/2000	160	4.4	4.4	4.7
		5/04/2000	245	12.5	11	12.5
	*	6/07/2000	337	19.8	18.5	16.8
	**	13/09/2000	406	19.9	18.3	14.6
Purity (%)		11/01/2000	160	57.1	49.7	53.5
		5/04/2000	245	83.9	81.4	83
		6/07/2000	337	93	91.6	91
	**	13/09/2000	406	94.7	92.8	85.6
Stalk biomass (t ha-1)		11/01/2000	160	17.2	19.9	19.8
		5/04/2000	245	31.8	27.4	31.4
		6/07/2000	337	37.9	38.5	34.4
		13/09/2000	406	40.1	37.4	33.5
Stalk dry matter content (g DW g-1 FW)		11/01/2000	160	0.169	0.17	0.174
		5/04/2000	245	0.242	0.219	0.234
		6/07/2000	337	0.279	0.284	0.268
		13/09/2000	406	0.303	0.291	0.287
Stalk fibre (t ha-1)		5/04/2000	160	15.8	13.9	15.3
		6/07/2000	245	18.3	19.1	17
		13/09/2000	337	19.6	18.9	16.5
	*	11/01/2000	406	9.88	10.5	11.1
Stalk fibre concentration (g g-1 DW)		11/01/2000	160	0.576	0.53	0.562
		5/04/2000	245	0.497	0.508	0.488
		6/07/2000	337	0.486	0.496	0.496
		13/09/2000	406	0.487	0.505	0.496
Stalk fibre concentration (g g-1 FW)		11/01/2000	160	0.0977	0.09	0.098
		5/04/2000	245	0.12	0.111	0.114
		6/07/2000	337	0.135	0.141	0.133
		13/09/2000	406	0.148	0.147	0.142
Stalk number (m-2)		11/01/2000	160	9	9.1	10.1
		5/04/2000	245	8.6	8.7	8.8
		13/09/2000	337	8.3	7.5	7.4

	**	6/07/2000	406	8.2	7.8	7.8
Stalk sucrose concentration (g g-1 DW)		11/01/2000	160	0.256	0.222	0.235
		5/04/2000	245	0.392	0.401	0.4
		6/07/2000	337	0.526	0.479	0.491
	*	13/09/2000	406	0.5	0.488	0.439
Stalk sucrose concentration (g g-1 FW)		11/01/2000	160	0.0435	0.0377	0.041
		5/04/2000	245	0.0948	0.0878	0.0934
		6/07/2000	337	0.146	0.136	0.131
	**	13/09/2000	406	0.151	0.142	0.125
Stalk sucrose yield (t ha-1)		11/01/2000	160	4.4	4.41	4.67
		5/04/2000	245	12.5	11	12.5
	*	6/07/2000	337	19.8	18.5	16.8
	**	13/09/2000	406	19.9	18.3	14.6

Table 7.4. Commercial yields of crops harvested on 18/9/00 and grown under different irrigation schedules. Irrigation was scheduled after a specified soil water deficit below the Drained Upper Limit was reached. All crops were irrigated after 120 mm pan evaporation prior to canopy closure and irrigation was terminated 33 days prior to harvest for drying-off. Statistical analysis showed no significant difference at p=0.05.

Variate	Q99 1R Irrig 79 mm Soil Water Deficit	Q99 1R Irrig 123 mm Soil Water Deficit	Q99 1R Irrig 191 mm Soil Water Deficit
Cane yield (t ha^{-1})	169	173	153
Unadjusted Pol	12.7	13.4	12.3
Adjusted Pol (+1.0)	13.7	14.4	13.3
Pol yield (t ha^{-1}) using adjusted pol	23.5	25.0	20.4

Second ratoon experiment

Stalk population responded over time much the same as it did in the plant and first ratoon experiments (Table 7.5). Loss of stalks after the wet season was not marked and stalk population at harvest was greater than was case in the first ratoon. Declining performance with successive ratoons was therefore not evident in stalk population as a yield component (Table 7.5). Irrigation treatment had no significant effect on stalk population.

Leaf area index was not affected significantly by treatment but LAI decreased with decreasing irrigations when the crop was sampled in July as well as in September (Table 7.5). LAI was as low as 1.0 in the driest treatment in September indicating that this crop was suffering considerably from water stress at this stage. Green leaf number per stalk is perhaps a better indication of the degree of water stressed endured by the crop. In July green leaves per stalk were significantly lower in the high deficit treatments than in the 79 mm deficit treatment. In September the 191 mm treatment had stalks with only four mature green leaves indicating a severe degree of water stress. One or two mature green leaves indicate very severe stress when stalks may not recover if they are irrigated.

Cane biomass yield at harvest was reduced significantly by allowing the crop to extract 123 mm and 191 mm water before irrigating (Table 7.5). Both the 123 mm and 191 mm treatments led to a decrease in cane biomass yield at harvest, however the change in the yield of these treatments over the life of the crop made interesting reading even if the differences were not significant. In December yield appeared to *increase* with increasing deficits. In April and June the greatest yields appeared to be obtained with the medium deficit treatment (123 mm) whereas at harvest in September the greatest yield was obtained clearly in the 79 mm deficit treatment. This may indicate that 123 mm deficits could have been tolerated up to June but not between June and September. We know that the crop tolerates larger deficits in cool and cloudy conditions than in hot and sunny conditions which is possibly what these data indicate. It may be necessary to vary the allowable deficit through the season to make best use of the water and to minimise yield loss. This concept would need to be tested more thoroughly.

The effects of irrigation treatment on cane yield and cane biomass were similar. Cane yield at harvest was reduced 19.4 t/ha by irrigating at a 123 mm deficit compared to a 79 mm deficit and it was reduced a further 22.1 t/ha by irrigating at a 191 mm deficit rather than a 123 mm deficit. These yield reductions are considerably greater than was the case for the first ratoon experiment (3 and 12 t/ha loss respectively). It is not certain if this is due to the age of the ratoon, date of ratooning or climatic factors. However the results of the second ratoon experiment need to be considered when recommending that growers allow deficits greater than 79 mm to develop before irrigating. A more comprehensive analysis of the second ratoon results will be conducted together with model analysis in a new irrigation research and extension project (CSE007).

Sucrose content on a dry and fresh weight basis was not affected significantly by irrigation treatment but sucrose content was highest in the 123 mm treatment in June and in September (Table 7.5). In September, dry matter content was also highest in this treatment and in this case the effect was nearly significant (p=0.59) thus offering some basis for accepting that the greater sucrose content in the 123 mm treatment was real. Sucrose yield was 17.2 t/ha under the most liberal irrigation regime, 15.1 t/ha under the medium regime and only 11.2 t/ha under the low irrigation regime. 2.1 t sucrose/ha was lost by delaying irrigation until soil water deficit reached 123 mm rather than 79 mm. This was slightly more than the 1.6 t/ha yield loss under similar circumstances in the first ratoon experiment. A further loss of 5.9 t sucrose/ha by delaying irrigation until soil water deficit reached 191 mm was also slightly more than the loss of 5.3 t/ha achieved by a similar delay in the first ratoon experiment. In this sense, the results of the first ratoon experiment were repeated in the second ratoon experiment, adding weight to the conclusions from both experiments.

Table 7.5. Second ratoon results of irrigation scheduling trial (#446) growth analysis, Block 2B, Frank Wise Institute, Q99 2R Ratooned 18/09/00

Variate	Sampling date	Days after ratooning	Significance (p)	Q99 2R 79 mm Soil Water Deficit	Q99 2R 123 mm Soil Water Deficit	Q99 2R 191 mm Soil Water Deficit	Mean
Dead leaf number per stalk	19/12/2000	92	0.000				
	12/04/2001	206	0.130	13.1	15.0	14.3	14.1
	26/06/2001	281	0.733	17.1	18.1	17.9	17.7
	13/09/2001	360	0.219	25.0	23.5	23.6	24.0
Green leaf number per stalk	19/12/2000	92	0.179	9	8.7	9.8	9.2
	12/04/2001	206	0.794	8.8	9.0	9.0	8.9
	26/06/2001	281	0.022	10.0	9.4	8.1	9.2
	13/09/2001	360	0.073	7.0	7.3	4.0	6.1

Total leaf number per stalk	19/12/2000	92	0.000				
	12/04/2001	206	0.222	21.9	24.1	23.3	23.1
	26/06/2001	281	0.595	27.2	27.6	26.0	26.9
	13/09/2001	360	0.072	31.9	30.8	27.6	30.1
Total stalk number per m^2	19/12/2000	92	0.434	22	24.2	22.1	22.8
	12/04/2001	206	0.374	10.6	11.0	10.1	10.6
	26/06/2001	281	0.936	9.7	10.3	9.9	10.0
	13/09/2001	360	0.637	9.6	9.2	9.8	9.5
Leaf area per gram DM (cm^2/g)	19/12/2000	92	0.100	151.4	138.1	144.6	144.7
	12/04/2001	206	0.089	103.1	107.5	113.9	108.2
	26/06/2001	281	0.320	87.8	88.7	90.7	89.1
	13/09/2001	360	0.540	66.6	63.8	69.5	66.6
Leaf area index	19/12/2000	92	0.919	4.9	5	4.8	4.9
	12/04/2001	206	0.308	3.3	3.7	3.5	3.5
	26/06/2001	281	0.481	3.3	3.0	2.6	3.0
	13/09/2001	360	0.182	2.0	1.7	1.0	1.6
Leaf area per stalk(cm^2)	19/12/2000	92	0.608	2230	2083	2190	2168
	12/04/2001	206	0.212	3102	3361	3481	3315
	26/06/2001	281	0.055	3392	2980	2618	2997
	13/09/2001	360	0.122	2034	1833	967	1611
Dry matter content of green leaf	19/12/2000	92	0.360	0.309	0.295	0.297	0.300
	12/04/2001	206	0.246	0.330	0.320	0.315	0.322
	26/06/2001	281	0.147	0.348	0.345	0.338	0.344
	13/09/2001	360	0.143	0.395	0.380	0.411	0.395
Dry matter content of mature stem	19/12/2000	92	0.284	0.094	0.095	0.099	0.096
	12/04/2001	206	0.802	0.240	0.243	0.242	0.242
	26/06/2001	281	0.059	0.299	0.297	0.287	0.294
	13/09/2001	360	0.367	0.300	0.309	0.295	0.301
Dry matter content of cabbage	19/12/2000	92	0.576	0.141	0.139	0.139	0.140
	12/04/2001	206	0.703	0.201	0.198	0.195	0.198
	26/06/2001	281	0.287	0.227	0.241	0.223	0.230
	13/09/2001	360	0.183	0.305	0.266	0.286	0.286
Dry matter content of trash	19/12/2000	92	0.230	0.870	0.894	0.913	0.892
	12/04/2001	206	0.000	0.000	0.000	0.000	0.000
	26/06/2001	281	0.005	0.895	0.906	0.922	0.908
	13/09/2001	360	0.562	0.893	0.899	0.914	0.902
Dry matter content of stalk and cabbage	19/12/2000	92	0.989	0.118	0.117	0.117	0.117
	12/04/2001	206	0.885	0.235	0.238	0.236	0.236
	26/06/2001	281	0.061	0.291	0.292	0.282	0.288
	13/09/2001	360	0.503	0.301	0.306	0.294	0.300
Dry matter content of cabbage & green leaf	19/12/2000	92	0.425	0.185	0.180	0.182	0.182
	12/04/2001	206	0.568	0.254	0.246	0.245	0.248
	26/06/2001	281	0.164	0.285	0.288	0.275	0.283
	13/09/2001	360	0.074	0.340	0.312	0.332	0.328
Dry matter content of total biomass	19/12/2000	92	0.785	0.146	0.145	0.143	0.145
	12/04/2001	206	0.970	0.256	0.256	0.257	0.256
	26/06/2001	281	0.047	0.309	0.310	0.302	0.307
	13/09/2001	360	0.341	0.326	0.329	0.343	0.333
Dry matter content of total biomass less trash	19/12/2000	92	0.785	0.146	0.145	0.143	0.145
	12/04/2001	206	0.921	0.242	0.244	0.242	0.243
	26/06/2001	281	0.049	0.296	0.296	0.285	0.292
	13/09/2001	360	0.441	0.305	0.310	0.298	0.304
Sucrose content of stalks (DM basis)	19/12/2000	92	0.000				
	12/04/2001	206	0.065	0.377	0.401	0.416	0.398

	26/06/2001	281	0.802	0.452	0.460	0.456	0.456
	13/09/2001	360	0.955	0.457	0.464	0.450	0.457
Sucrose content of stalks (FM basis)	19/12/2000	92	0.000				
	12/04/2001	206	0.079	0.090	0.098	0.101	0.096
	26/06/2001	281	0.478	0.135	0.137	0.131	0.134
	13/09/2001	360	0.677	0.137	0.144	0.131	0.137
Fibre content of stalks (DM basis)	19/12/2000	92	0.000				
	12/04/2001	206	0.200	0.528	0.510	0.509	0.516
	26/06/2001	281	0.924	0.489	0.492	0.491	0.491
	13/09/2001	360	0.441	0.521	0.508	0.535	0.521
Purity (%)	19/12/2000	92	0.000				
	12/04/2001	206	0.095	80.3	83.3	82.7	82.1
	26/06/2001	281	0.544	88.8	89.4	87.9	88.7
	13/09/2001	360	0.657	88.0	90.2	83.2	87.1
Brix	19/12/2000	92	0.000				
	12/04/2001	206	0.095	14.2	14.8	15.3	14.8
	26/06/2001	281	0.316	19.8	20.0	19.3	19.7
	13/09/2001	360	0.672	20.8	21.4	21.0	21.1
Fraction of trash in total biomass	19/12/2000	92	0.394	0.073	0.066	0.080	0.073
	12/04/2001	206	0.000	0.000	0.000	0.000	0.000
	26/06/2001	281	0.368	0.062	0.070	0.077	0.070
	13/09/2001	360	0.008	0.094	0.087	0.192	0.124
Fraction of cabbage in total biomass	19/12/2000	92	0.423	0.412	0.410	0.379	0.400
	12/04/2001	206	0.155	0.084	0.088	0.079	0.084
	26/06/2001	281	0.711	0.068	0.066	0.061	0.065
	13/09/2001	360	0.147	0.071	0.067	0.043	0.060
Fraction of green leaf in total biomass	19/12/2000	92	0.120	0.318	0.316	0.297	0.310
	12/04/2001	206	0.467	0.096	0.093	0.091	0.093
	26/06/2001	281	0.004	0.094	0.079	0.076	0.083
	13/09/2001	360	0.140	0.060	0.063	0.038	0.054
Fraction of stalk in total biomass	19/12/2000	92	0.288	0.270	0.275	0.323	0.289
	12/04/2001	206	0.906	0.747	0.752	0.751	0.750
	26/06/2001	281	0.748	0.775	0.786	0.785	0.782
	13/09/2001	360	0.000	0.774	0.783	0.727	0.761
Fraction of stalk and cabbage in total biomass	19/12/2000	92	0.120	0.682	0.684	0.703	0.690
	12/04/2001	206	0.614	0.831	0.841	0.830	0.834
	26/06/2001	281	0.721	0.844	0.852	0.846	0.847
	13/09/2001	360	0.002	0.845	0.849	0.770	0.821
Fraction of cabbage and green leaf in total biomass	19/12/2000	92	0.288	0.730	0.725	0.677	0.711
	12/04/2001	206	0.164	0.180	0.182	0.170	0.177
	26/06/2001	281	0.173	0.162	0.144	0.137	0.148
	13/09/2001	360	0.122	0.132	0.130	0.081	0.114
Cane yield (t/ha)	19/12/2000	92	0.468	29.3	33.0	36.9	33.1
	12/04/2001	206	0.313	103.8	113.5	106.2	107.8
	26/06/2001	281	0.751	103.1	115.0	102.9	107.0
	13/09/2001	360	0.038	125.5	106.1	84.0	105.2
Cane yield + dead stalks and suckers (t/ha)	19/12/2000	92	0.468	29.3	33.0	36.9	33.1
	12/04/2001	206	0.313	103.8	113.5	106.2	107.8
	26/06/2001	281	0.751	103.1	115.0	102.9	107.0
	13/09/2001	360	0.038	125.5	106.1	84.0	105.2
Cane + cabbage yield (t/ha)	19/12/2000	92	0.433	59.0	66.6	67.3	64.3
	12/04/2001	206	0.303	117.7	129.9	120.1	122.6
	26/06/2001	281	0.765	115.1	126.7	113.3	118.4
	13/09/2001	360	0.042	136.8	116.6	89.3	114.2

DM of green leaf (g/m^2)	19/12/2000	92	0.474	325	362	332	340
	12/04/2001	206	0.296	320	343	309	324
	26/06/2001	281	0.361	375	340	286	334
	13/09/2001	360	0.066	293	264	134	230
Cane biomass (g/m^2)	19/12/2000	92	0.279	275	312	362	316
	12/04/2001	206	0.330	2491	2765	2576	2611
	26/06/2001	281	0.693	3076	3427	2956	3153
	13/09/2001	360	0.048	3768	3266	2446	3160
DM of cabbage (g/m^2)	19/12/2000	92	0.530	418	469	425	437
	12/04/2001	206	0.205	280	324	272	292
	26/06/2001	281	0.639	272	284	231	262
	13/09/2001	360	0.104	351	282	149	261
DM of trash (g/m^2)	19/12/2000	92	0.725	242	243	270	252
	12/04/2001	206	0.000	0	0	0	0
	26/06/2001	281	0.585	249	295	295	280
	13/09/2001	360	0.009	459	365	638	487
DM of stalk and cabbage (g/m2)	19/12/2000	92	0.305	693	781	787	754
	12/04/2001	206	0.305	2771	3089	2848	2903
	26/06/2001	281	0.683	3349	3711	3187	3416
	13/09/2001	360	0.049	4119	3549	2595	3421
DM of cabbage and green leaf (g/m^2)	19/12/2000	92	0.493	743	831	757	777
	12/04/2001	206	0.200	600	667	581	616
	26/06/2001	281	0.493	647	624	517	596
	13/09/2001	360	0.079	644	547	282	491
DM of total biomass (g/m^2)	19/12/2000	92	0.385	1018	1143	1120	1094
	12/04/2001	206	0.365	3333	3675	3427	3478
	26/06/2001	281	0.704	3972	4347	3768	4029
	13/09/2001	360	0.072	4870	4178	3366	4138
DM of total biomass minus trash (g/m^2)	19/12/2000	92	0.385	1018	1143	1120	1094
	12/04/2001	206	0.290	3091	3432	3157	3227
	26/06/2001	281	0.687	3723	4051	3473	3749
	13/09/2001	360	0.046	4412	3813	2728	3651
Sucrose yield (g/m^2)	19/12/2000	92	0.000				
	12/04/2001	206	0.216	937	1112	1078	1042
	26/06/2001	281	0.668	1394	1577	1342	1438
	13/09/2001	360	0.115	1720	1511	1115	1449
Fibre yield (g/m^2)	19/12/2000	92	0.000				
	12/04/2001	206	0.355	1315	1408	1310	1344
	26/06/2001	281	0.694	1504	1688	1456	1549
	13/09/2001	360	0.036	1953	1659	1316	1643
Fresh cane mass per stalk (g)	19/12/2000	92	0.454	133	141	167	147
	12/04/2001	206	0.248	978	1042	1052	1024
	26/06/2001	281	0.028	1064	1123	1035	1074
	13/09/2001	360	0.002	1306	1150	856	1104
Dry cane mass per stalk (g)	19/12/2000	92	0.277	13	13	16	14
	12/04/2001	206	0.342	234	254	254	247
	26/06/2001	281	0.009	317	333	298	316
	13/09/2001	360	0.006	391	355	250	332
Dry total biomass per stalk (g)	19/12/2000	92	0.481	46	48	51	48
	12/04/2001	206	0.294	314	336	338	329
	26/06/2001	281	0.035	409	425	379	404
	13/09/2001	360	0.010	506	454	344	435

Conclusions from three irrigation scheduling experiments in Field 2B

The highest sucrose yields were obtained by the most frequent irrigation regimes in all three experiments. Sucrose yield losses of 1.6 to 2.1 t/ha by irrigating less frequently was not large when considering the total amount of water saved (Table 7.6). The risk of substantial yield loss by irrigating at deficits greater than 123 mm would not justify the considerable further savings of irrigation. Irrigating when about 50 % of the plant available water capacity has been used appears to be a reasonable compromise between maximizing sucrose yield and minimizing off site impacts associated with irrigation particularly the impact of irrigation on rising ground water levels and on the quality and quantity of runoff returning to the river system. However, until further research is conducted to understand the basis of these responses and their wider applicability across different seasons and soil types, caution should be exercised in the yield/water application trade-off. Nevertheless, the potential exists for more sustainable irrigation practices.

Table 7.6. Yields obtained by hand sampling and number of irrigations and amount of water applied from channel to field for different irrigation treatments for both the plant and subsequent ratoon crops.

Plant Crop planted 6/5/98 and harvested 449 dap	Irrigate at 60mm pan evaporation	Irrigate at 120mm pan evaporation	Irrigate at 180mm pan evaporation
Cane Yield (t/ha)	184	174	177
Sucrose Yield (t/ha)	24.2	22.3	22.0
Number of irrigations	28	19	15
Amount of water applied (ML ha^{-1})	41.3	44.0	33.3
First ratoon crop ratooned 4/8/99 and harvested 406 dap	Irrigate at 79mm soil water deficit	Irrigate at 123mm soil water deficit	Irrigate at 191mm soil water deficit
Cane Yield (t/ha)	132	129	117
Sucrose Yield (t/ha)	19.9	18.3	14.6
Number of irrigations	21	13	9
Amount of water applied (ML ha^{-1})	33.3	24.5	19.4
Second ratoon crop ratooned 18/9/00 and harvested 360 dap	Irrigate at 79mm soil water deficit	Irrigate at 123mm soil water deficit	Irrigate at 191mm soil water deficit
Cane Yield (t/ha)	126	106	84
Sucrose Yield (t/ha)	17.2	15.1	11.1
Number of irrigations			
Amount of water applied (ML ha^{-1})			

Stalk elongation measurements

As part of the work being conducted in the Ord, stalk elongation rates were measured as a means of providing additional information to help explain irrigation trial outcomes and as a possible option for scheduling irrigation. Stalk elongation rates were measured for a short period in a first ratoon crop grown in bay 2B on the Frank Wise Institute, to establish likely growth rates (Fig. 7.18). These results indicate that while stalk elongation generally responds to irrigation, the response is variable, with a possibly higher initial rate of stalk elongation following wetting of drier soil. This in turn could indicate compensatory growth in response to irrigation or rainfall at larger soil moisture deficits. Other work has also indicated a possible relationship between rate of stalk elongation and depth of drying of the soil moisture profile.

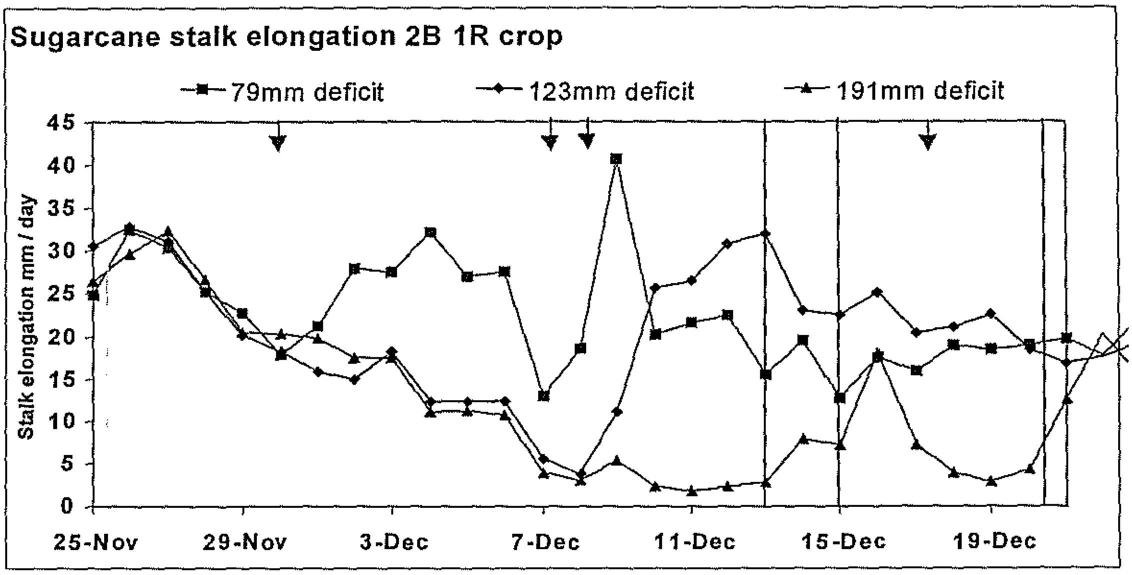


Figure 7.18. Change in rate of stalk elongation for a first ratoon crop of Q99 ratooned on 4 August 1999. Irrigation occurred at three deficits indicated with rainfall events represented by vertical lines.

Several other commercial sites in the ORIA were also selected for stalk elongation investigations, with a number of growers taking part in this exercise. At one of these sites, block 27-4, stalk elongation measurements were carried out in conjunction with soil moisture assessment using EnviroSCAN equipment. The results of this exercise are presented in Figure 7.19 below.

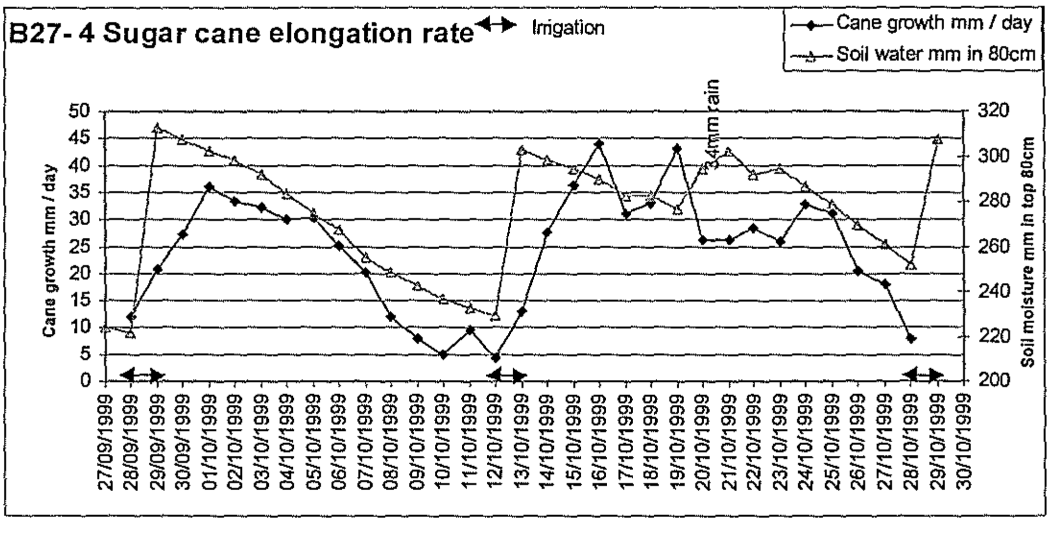


Figure 7.19. Daily cane stalk elongation and soil moisture to a depth of 800mm.

The results from B27 also indicate that as soil moisture depleted stalk elongation decreased. However, these results also indicate some inconsistency in the relationship between soil moisture levels and rate of elongation with different rates occurring at different soil moisture levels for different irrigation cycles. Other blocks examined utilised the BSES method of irrigation scheduling ie. re-irrigating once rate of elongation reduces to 50% of maximum.

For a crop at canopy closure in September – December, this method indicated that re-irrigation should occur approximately every 7 days. This result was inconsistent with irrigation trial results which indicated that less frequent irrigation would result in similar yield at harvest, possibly resulting from compensatory 'catch up' growth for less frequently watered crops, with wet season rains. Based on the above results, further investigation would be required before utilising this method commercially in the Ord.

8. WATER EXTRACTION BY SUGARCANE ON DIFFERENT SOILS

Introduction

In irrigated cropping systems the goal is to maximise profitability whilst exploiting opportunities to save water and improve crop water use efficiency and hence conserve the environment. Determining the best-bet irrigation strategy requires knowledge of the crop water requirement at different stages of growth under variable climatic conditions and the capacity of the soil, both to store rainfall and irrigation water and to supply water to meet crop growth requirements. The soil water holding capacity depends both on the available water capacity in the soil and the depth of crop extraction.

Sugarcane is a new commercial crop in the ORIA and little information is available on plant extractable soil water (PESW) and soil water extraction at different depths of the soil profile for sugarcane growing in the ORIA. This information is required to parameterise cropping systems models such as APSIM Sugarcane (Keating *et al.*, 1999). Given year-to-year variability in climate, different soil types and variable cropping cycles in sugarcane production, cropping systems models are a valuable, if not essential tool, to determine irrigation water requirements and yield responses to different irrigation schedules. The use of the modelling approach with historical climatic data overcomes the year-specific and site-specific limitation of field experimentation.

There is limited information on maximum extractable water per unit soil depth for sugarcane in Australia (Inman-Bamber *et al.* 2000). Baran *et al.* (1974) found 180 mm was extracted from a 2.0 m profile by sugarcane and Koehler *et al.* (1982) recorded extractable soil water of 160 mm to 1.5 m. For a grey cracking silty clay, Inman-Bamber *et al.* (1999) observed that water was extracted at least to a depth of 1.8 m and the PESW was 130 mm, with considerable extraction below 1.0 m. Thompson (1976) found that irrigated sugarcane did not remove water from depths greater than 90 cm on a clay soil, but water was extracted to a depth of 180 cm on a sandy soil. However, variable depth of soil water extraction may not necessarily be production system specific, but may be due to an insufficient period of soil drying to allow full extraction of all the available water. Hence, there is a need to use standardised procedures to quantify the soil water supply to sugarcane in different production systems.

Ratcliff *et al.* (1983) found that across a wide range of soil textures, various annual crops extracted a narrow range (100-120 mm) of water per metre of soil, except for sandy soils where the value was around 60mm/m. Bridge *et al.* (1982) reported the available water in Cununuura clay to be 140 mm/m. These results, and those detailed by Baran *et al.* (1974), Koehler *et al.* (1982) and Inman-Bamber *et al.* (1999) suggest that sugarcane is capable of extracting similar amounts of water/unit soil depth as other crops. So, there is a need to quantify both the PESW and the extent of soil water extraction with depth for specific soil types in a given location. Inman-Bamber *et al.* (1998) report on the importance of the amount of water available to the sugarcane plant below the readily available limit in the identification of management strategies to maximise profitability rather than productivity.

There are two common soil types of the Ivanhoe Plain in the ORIA, the Cununurra clay and the Aquitaine. Aldrick *et al.* (1990) describes these cracking clay soils and the boundaries of the soil types. The Cununurra clay soils have a clay content of around 60% in the north and are dark greyish brown changing to reddish medium clay at 140 to 160 cm. In the south, the clay content is lower at around 45% and the soils are dark brownish changing to reddish light to medium clay at 140 to 160 cm. The Aquitaine soils located in the north-east of the Ivanhoe Plain have higher clay content of around 75% and are dark grey changing to brownish medium to heavy clay at 130 to 150 cm.

Development of management strategies for best practice irrigation of sugarcane requires a detailed knowledge of sugarcane water requirements. High evaporation rates are recorded in the ORIA and correspondingly high water use by sugarcane is expected. The comparison of the measured water use by sugarcane with class A pan evaporation at specific sites will enable irrigation scheduling methods to be developed to suit crop requirements.

The primary objective of this section is to quantify PESW and the pattern of soil water extraction by sugarcane when grown on a range of soil types in the ORIA. A second objective is to quantify the rate of crop water use compared to class A pan evaporation throughout the crop cycle for sugarcane growing under different irrigation regimes in the Ord environment.

Materials and Methods

Soil water characteristics (PESW, drained upper limit (DUL) and lower limit (LL)) of Cununurra clay and Aquitaine were studied on the Ivanhoe Plain of the ORIA (15.65°S, 128.72°E). Four sites were selected for study, three on Cununurra clay and one on Aquitaine soil types. The location and dates of determination are shown in Table 8.1 and the location mapped in Figure 8.1. The Central and Southern Ivanhoe Plain sites were located on brownish cracking clay. The Northern Ivanhoe Plain site is located on greyish cracking clay and the Aquitaine site has cracking clay with hydromorphic attributes and is in the greyish phase. All sites were within blocks growing sugarcane.

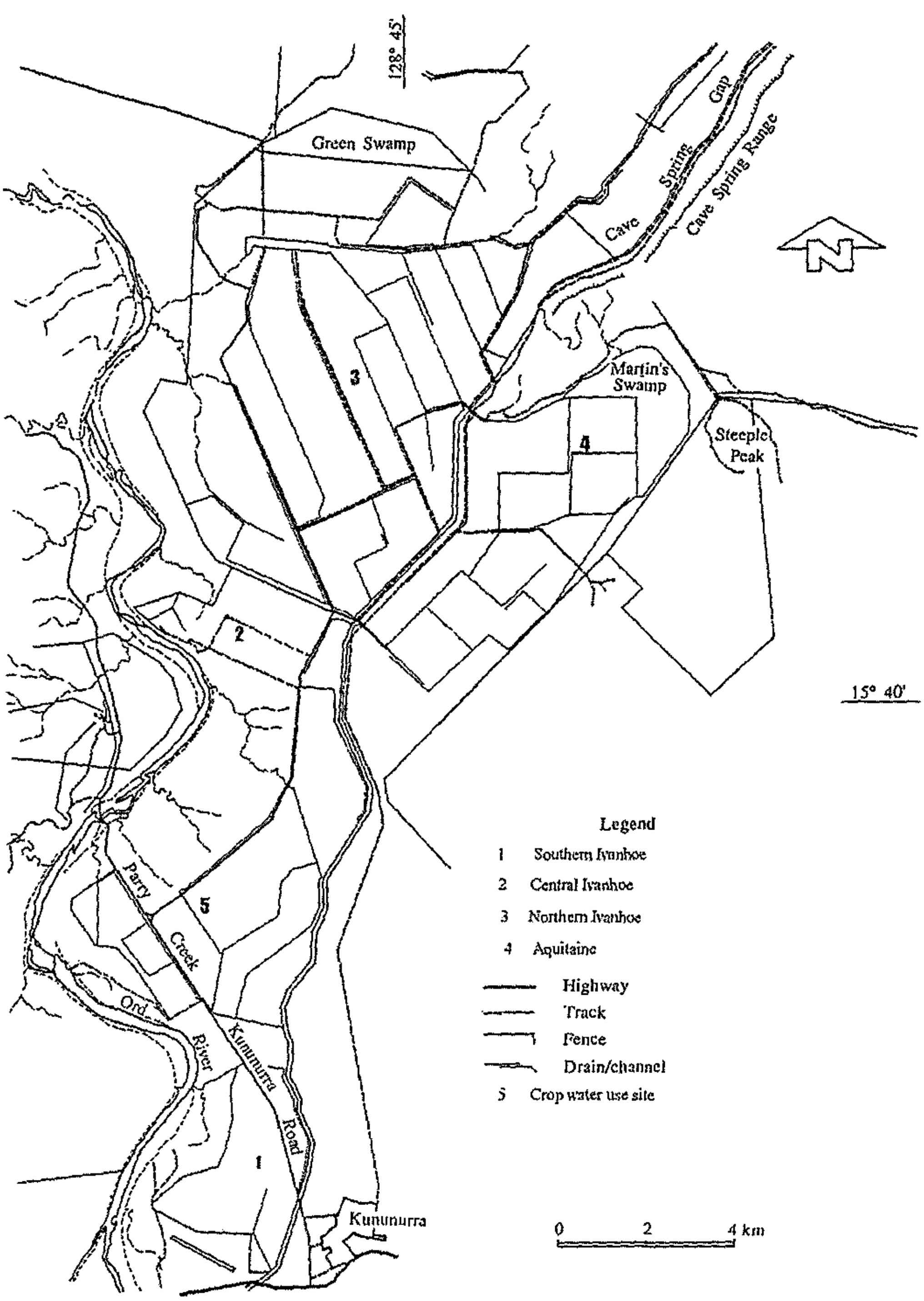
Table 8.1. Location of the four sites studied on the Ivanhoe Plain of the Ord River Irrigation Area including the dates of determination of the drained upper limit and the crop lower limit

Site Ord River Mill Field No.	Drained upper limit site installed	Drained upper limit site sampled	Crop lower limit site sampled
Southern Ivanhoe Plain B150-1-10	2/5/00	14/6/00	15/6/00, 13/7/00, 15/8/00, 19/9/00
Central Ivanhoe Plain 2B FWI	1/5/00	13/6/00	12/6/00, 13/7/00, 1/8/00 31/8/00
Northern Ivanhoe Plain B220-5-20	4/5/00	16/6/00	21/5/00, 15/8/00, 31/7/00
Aquitaine B250-2-20	5/5/00	15/6/00	13/7/00, 1/8/00, 20/9/00

Drained upper limit

After a record wet season (1662mm rainfall with the last rain on 24/4/00), 1.6 m soil moisture monitoring access tubes were installed in an uncropped area 5 m x 5 m. The site was bunded and ponded 3 times per week. Soil water content (SWC) was monitored weekly and the soil was considered to be saturated after one month, when SWC was constant. The site was covered with a black plastic sheet to prevent surface evaporation and was left to drain until readings stabilised after approximately 10 days and the profile was assumed to have drained. The soil was then sampled to 2 m using the field measurement mechanical sampling procedure for bulk density and DUL of Dalgliesh and Foale (1998). Gravimetric soil water and bulk density were determined for each 100mm depth increment using four cores at each site.

Figure 8.1. Ivanhoe Plain of the Ord River Irrigation Area Western Australia showing location of the soil water characterisation and crop water use sites.



As Cununurra clay and Aquitaine are "shrink-swell soils", bulk density changes with soil water content. The bulk density and then the volumetric water content of samples with lower water content was calculated using the equation:

$$\rho\theta = \rho_r / [\, \rho_r/\rho_s + \theta_w \cdot \rho_r + \varepsilon \,]^{1/3} \qquad \text{(Bridge and Muchow 1981)}$$

where $\rho\theta$ is the bulk density at a water content θ,
ρ_r is the fully wet reference bulk density (from DUL sites),
ρ_s is the density of soil solids (2.64 in Cununurra clay),
θ_w is the gravimetric water content,
ε is the air filled pore space (calculated from DUL bulk density and water content).

Lower limit of water extraction

Sites for determining the lower limit of water extraction were established in early May 2000 within commercial sugarcane crops ratooned after harvest in 1999, as detailed in Table 8.1 within the same block as the DUL sites. The crops were not irrigated until after harvest except for the Aquitaine site, which was irrigated until the end of May. Evaporation from the surface was minimised by applying a thick layer of mulch. Soil water content was monitored by soil sampling at 10 cm increments to 2 m depth. Three cores per site were taken at approximately monthly intervals (see Table 8.1). An indicator of crop stress was required to identify that a sufficient period of soil drying had occurred to allow the full extraction of all the available water. Crop stress was monitored by averaging the number of fully expanded green leaves on 10 stalks each week, except at Northern Ivanhoe. The crop lower limit was calculated from the gravimetric water content of the soil samples from the driest profiles and using the equation of Bridge and Muchow (1981).

Crop water use

Crop water use was measured at two additional sites. The first was in the sugarcane irrigation scheduling trial during the 1999/2000 growing season on the Central Ivanhoe Plain site (Table 8.1). Crops were grown under three irrigation regimes as outlined by Muchow, *et al.* (2001). Irrigation was scheduled after a soil water deficit of 79 (Treatment 1), 123 (Treatment 2) and 191 (Treatment 3) mm below the DUL in a 1.9 m profile. The second was in a commercial crop of plant cane Q96 (at Ord Sugar Mill Block No. 300-27-40) during the 1999/2000 growing season (Figure 8.1, site 5). Irrigation was scheduled on this cane on a regular cycle every two weeks in the absence of rain.

Neutron Moisture Meter (NMM) readings were taken the day before and 2 days after each irrigation at the Central Ivanhoe site from November 1999 to September 2000. This crop was ratooned after harvest in July 1999. Four access tubes were located in each of the three replicates, and data are presented as the mean of the readings from the 12 access tubes. Gravimetric soil water samples were taken for the 0-150 mm depth and NMM readings were taken with the neutron source at 100mm intervals between 200 and 1800 mm.

NMM readings were also taken the day before and two days after each irrigation from August to November 1999 within the crop planted in May 1999 at Ord Sugar Mill Block 300-27-40. Here 24 access tubes were located across the block and NMM readings were taken at the same depth increments as those done on Block 2B. Gravimetric soil water samples were taken for the 0-15 cm depth.

The crop water use per day was calculated as the difference between the soil water in the 1.9 m soil profile two days after irrigation and the soil water the day before the next irrigation averaged over the number of days. Crop water use for irrigation intervals in which rainfall occurred was not calculated. Class A pan evaporation and rainfall were recorded daily at the Frank Wise Institute weather station.

The NMM was calibrated at each site using the method of Greacen (1981). Regular volumetric soil moisture samples were taken around temporary access tubes throughout dry-down cycles at each site. The soil sample and NMM readings were used to establish a calibration curve for each depth at each site.

Results

Drained upper limit

There was considerable variation in the DUL across the four soil types at different depths in the profile (Figures 8.2b, 8.3b, 8.4b, and 8.5b). Aquitaine clay, with the highest clay content, retained the most water after drainage (1059 mm for a 2 m profile). The Cununurra clay sites retained similar total soil water in a 2 m profile (883 mm Northern Ivanhoe, 800 mm Southern Ivanhoe and 771 mm Central Ivanhoe). Soil type changes occurred at around 150 to 160 cm depth in Central and Southern Ivanhoe soils and deeper (180 cm) in Northern Ivanhoe and Aquitaine soils resulting in a change in the volumetric soil water occurring at this depth.

Lower limit of water extraction

The onset of stress was measured by the decline in the number of fully expanded green leaves per stalk as the soils dried (Figures 8.2a, 8.4a, and 8.5a). The rate of water use by the crops fell during the dry-down and the sugarcane at each site extracted low amounts of water between the last two sampling dates. Accordingly, the lower limit of extraction for the sugarcane crops on these soil types was measured on a dessicated crop with little water extraction occurring.

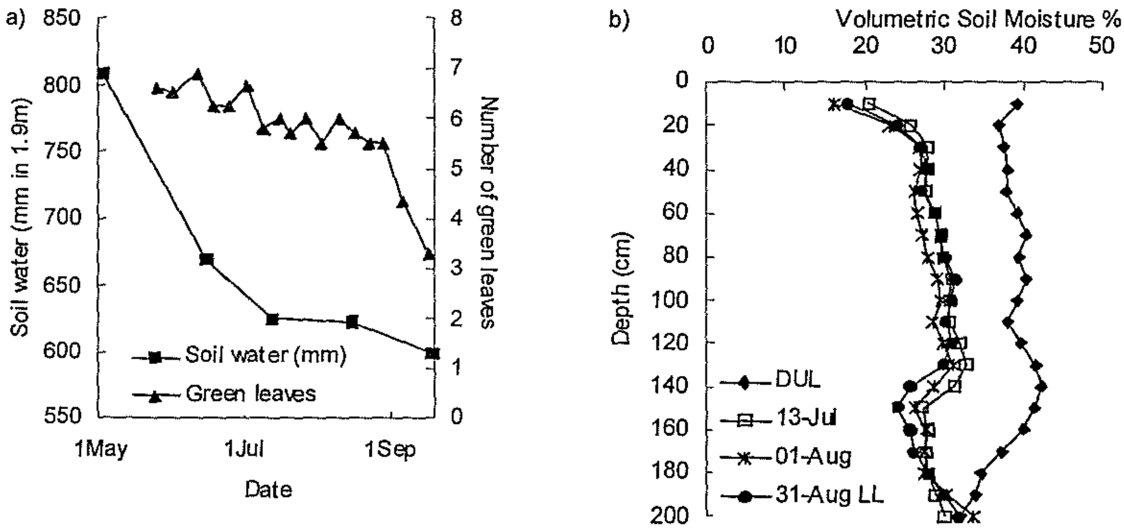


Figure 8.2. Central Ivanhoe Plain (a) change in total profile soil water storage and green leaf count during dry-down and (b) soil water profile of the drained upper limit and crop lower limit from gravimetric soil measurements.

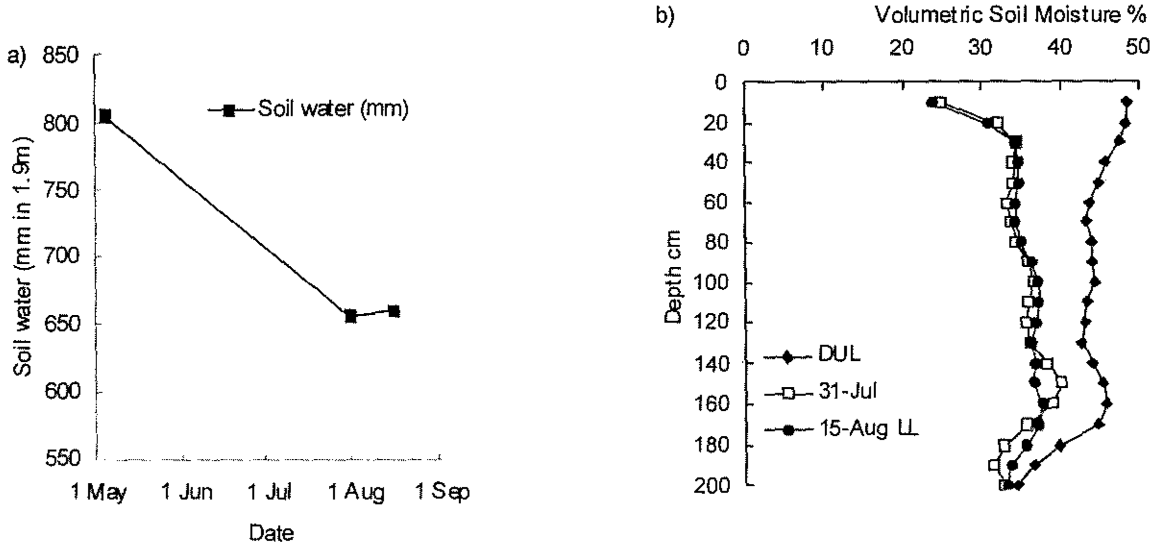


Figure 8.3. Northern Ivanhoe Plain (a) change in total profile soil water storage during dry-down and (b) soil water profile of the drained upper limit and crop lower limit from gravimetric soil measurements.

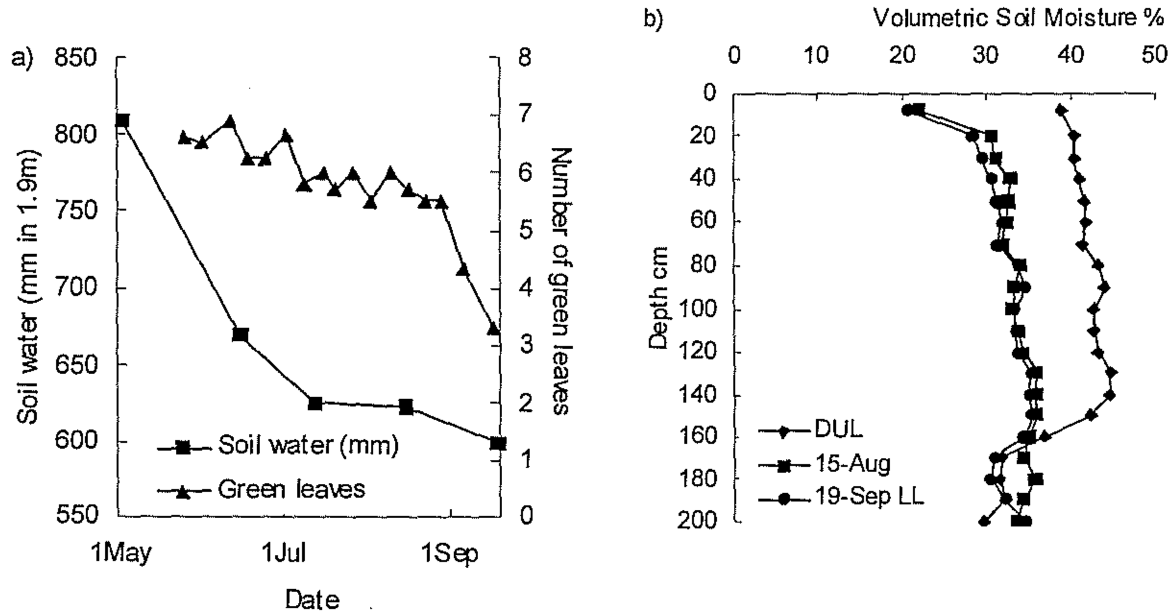


Figure 8.4. Southern Ivanhoe Plain (a) change in total profile soil water storage and green leaf count during dry-down and (b) soil water profile of the drained upper limit and crop lower limit from gravimetric soil measurements.

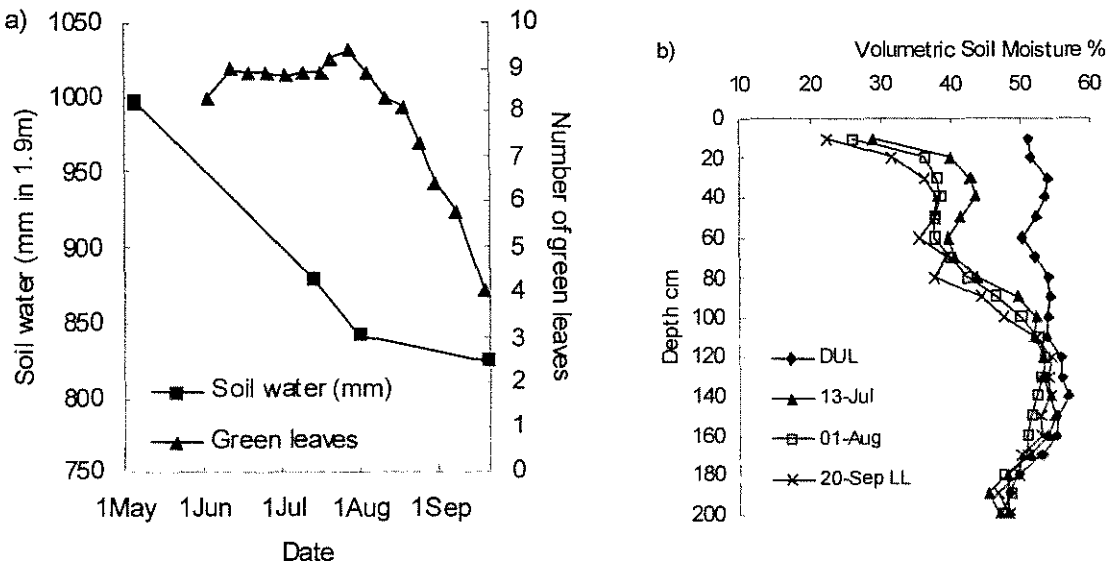


Figure 8.5. Aquitaine (a) change in total profile soil water storage and green leaf count during dry-down and (b) soil water profile of the drained upper limit and crop lower limit from gravimetric soil measurements.

The depth of extraction was 1.8 m at the Central and Northern Ivanhoe sites, 1.6 m at the Southern Ivanhoe site and little extraction occurred below 1 m at the Aquitaine site (Figures 8.2b, 3b, 4b, and 5b). Most extraction occurred in the top metre, but considerable extraction occurred below 1 m for each soil type, except in the Aquitaine soil (Table 8.2). The similarity in DUL and LL values at 2m indicates extraction did not occur below 1.9 m at any site. More water was held in the Aquitaine soil at the lower limit than the other soil types; 872 mm for a 2 m profile compared to 690 in the Northern Ivanhoe, 633 in Southern Ivanhoe and 545 mm for a 2 m profile in Central Ivanhoe.

Table 8.2. Plant extractable soil water (mm) calculated for four soils as the difference between the drained upper limit and lower limit of extraction for profile depths of 1.0, 1.9 and 2.0 m.

Soil	Profile Depth		
	1.0 m	1.9 m	2.0 m
Aquitaine	167	186	187
Northern Ivanhoe Plain	129	190	193
Southern Ivanhoe Plain	115	169	167
Central Ivanhoe Plain	128	225	226

PESW was highest in the Central Ivanhoe soils at 226 mm for a 2 m profile (Table 8.2). PESW for this soil is greater than previous information on maximum extractable soil water by sugarcane for a 2 m profile (Baran *et al.*, 1974), and to greater depth than Koehler *et al.* (1982). At Northern Ivanhoe PESW for a 2 m profile was 193 mm, 187 mm at Aquitaine and 166 mm at the Southern Ivanhoe site in accordance with Baran *et al.* (1974) who found 180 mm was extractable in a 2 m profile. The estimate of Inman-Bamber *et al.* (1999) for PESW of 130 mm over 1.8 m on grey cracking silty clays is much lower than that found on the Cununurra clay and Aquitaine soils of the ORIA.

Crop water use

The relevance of using PESW for irrigation scheduling was tested by monitoring the water content of two irrigated blocks of sugarcane. The profile soil water in 1.9 m for the Central Ivanhoe site varied through the growing season (Figure 8.6a). Treatment 1, which was irrigated at the lowest deficit of 79 mm (0.65 FESW), was irrigated more frequently than the other treatments after November 99 (14 irrigations). Treatment 2 (0.5 FESW) was irrigated 7 times and treatment 3 (0.15 FESW) was irrigated 3 times only. The rainfall during the 1999/2000 wet season was regular and little irrigation was necessary through the period from December 1999 to May 2000 (Figure 8.6b).

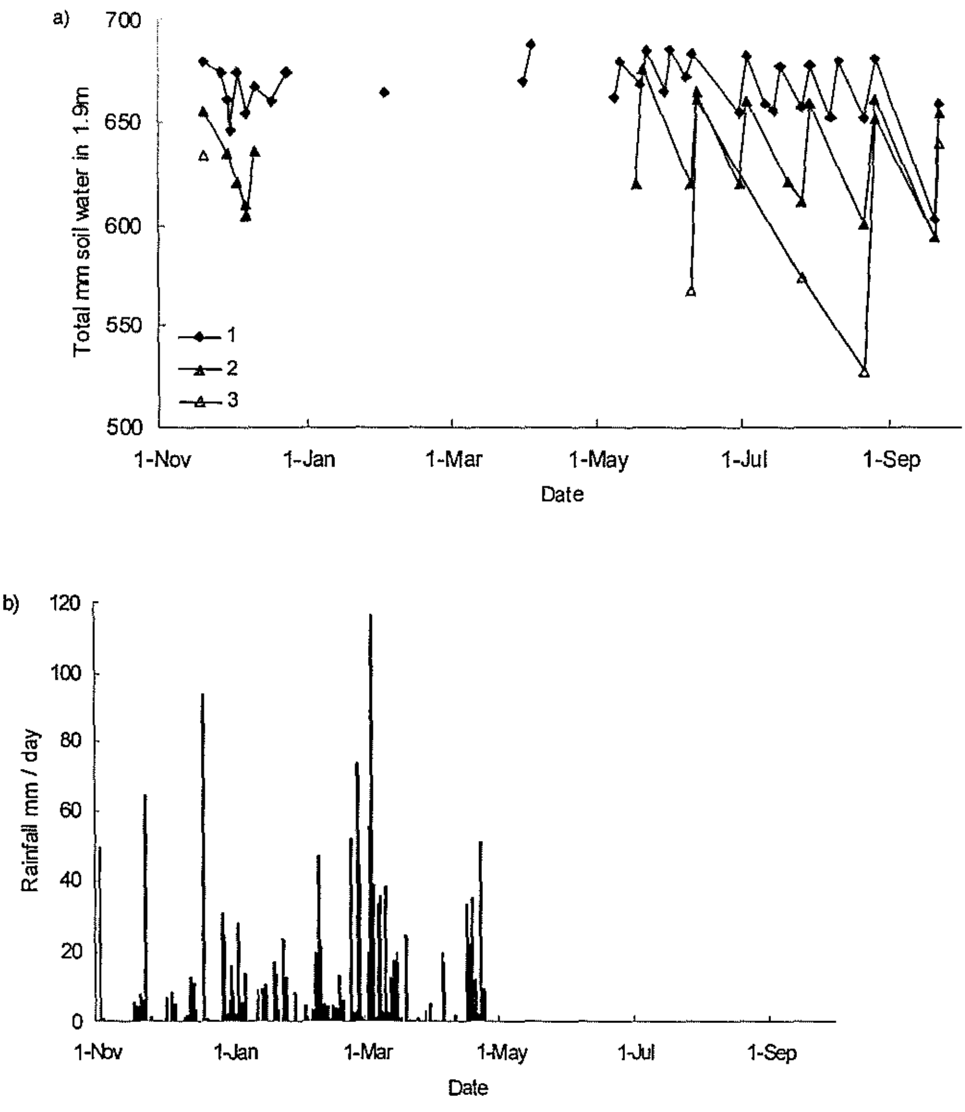


Figure 8.6. Central Ivanhoe Plain (a) profile soil water to 190 cm for the ratoon crop from neutron moisture meter readings taken the day before and two days after each irrigation (1 = irrigated at 79 mm soil water deficit, 2 = irrigated at 123 mm soil water deficit, 3 = irrigated at 191 mm soil water deficit) and (b) rainfall for Frank Wise Institute 1999/2000.

Drying the soil between irrigations caused the sugarcane to extract soil water to a greater depth (Figure 8.7). The NMM data at each depth for each treatment showed the extent of extraction for each treatment was different. The sugarcane extracted soil water to 60 cm depth in treatment 1, to 80 cm in treatment 2 and to 120 to 160 cm in treatment 3.

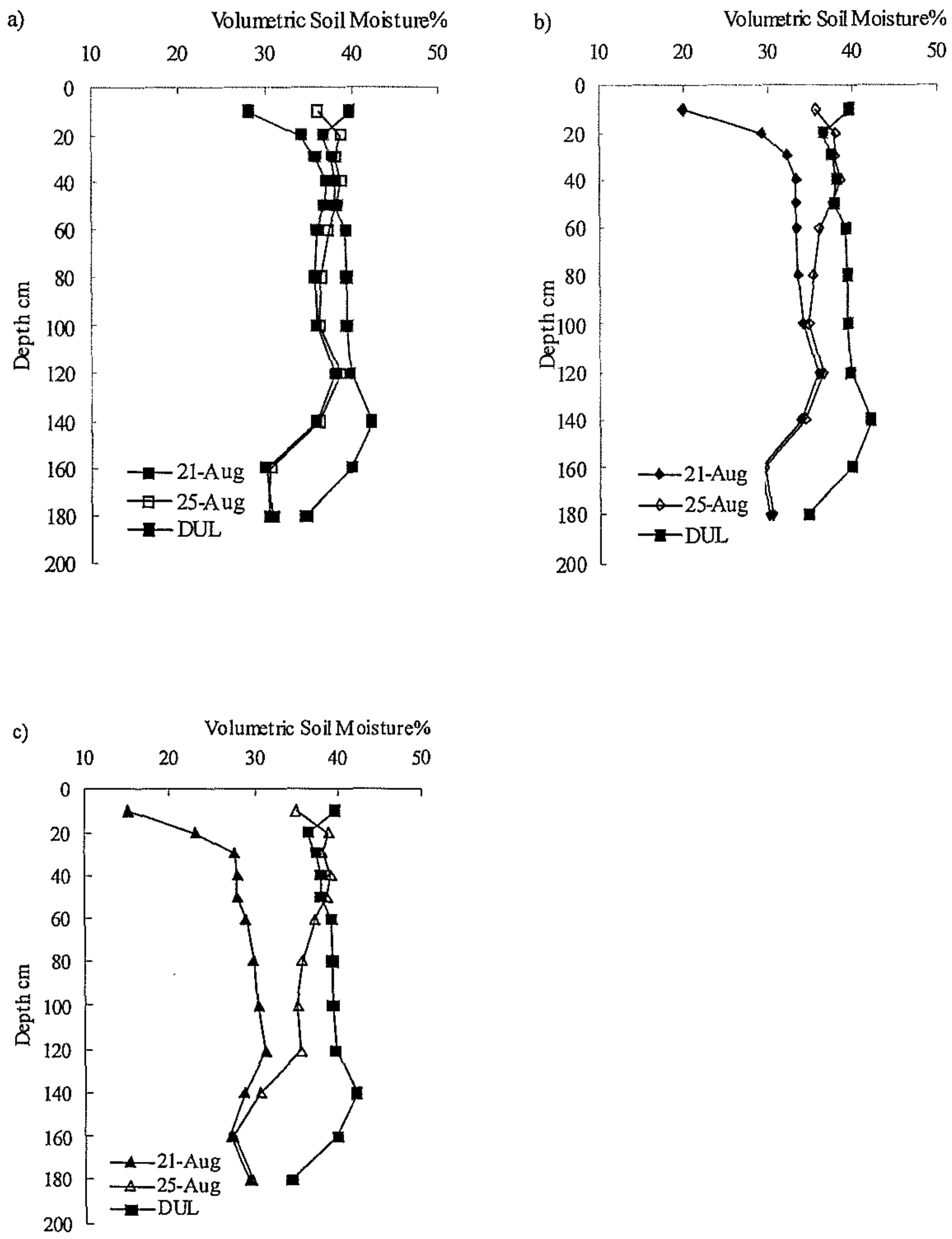


Figure 8.7. Sample profile soil water for Central Ivanhoe Plain ratoon crop from NMM readings at each depth for each treatment the day before and 2 days after irrigation and profile soil water from DUL site. a) irrigated at 79 mm soil water deficit, b) irrigated at 123 mm soil water deficit and c) irrigated at 191 mm soil water deficit.

However, the rate of water extraction between irrigations was similar for sugarcane grown under the different irrigation schedules (Table 8.3). The crop water use was high before the wet season but well below the daily class A pan evaporation after the wet season. The ratio of water use to pan evaporation was similar in treatment 1 and 2 and lower in treatment 3. This treatment was extreme and yield was reduced when irrigation was scheduled at 191mm, treatment 3 (Muchow *et al.*, 2001), but a reduction in yield did not occur between treatments 1 and 2.

Table 8.3. Central Ivanhoe Plain soil water use at each irrigation based on neutron moisture meter readings the day before and 2 days after each irrigation
(12 access tubes per treatment averaged at each date)

Irrigation Date	Water use (mm/day) since 2 days after last irrigation	Average pan evaporation (mm/day) since 2 days after last irrigation	Ratio water use / pan evaporation
Treatment 1			
30/11/99	6.95	6.12	1.136
20/5/00	1.35	5.94	0.227
30/5/00	2.78	5.40	0.515
8/6/00	2.17	5.50	0.395
1/7/00	1.37	5.03	0.272
15/7/00	2.39	4.51	0.530
27/7/00	2.14	5.29	0.405
8/8/00	2.79	5.57	0.501
22/8/00	2.56	5.75	0.445
19/9/00	3.09	7.01	0.441
Treatment 2			
10/6/00	2.77	5.50	0.504
1/7/00	2.44	5.03	0.485
27/7/00	2.10	5.29	0.397
22/8/00	2.50	5.75	0.435
19/9/00	2.71	7.01	0.387
Treatment 3			
22/8/00	1.91	5.75	0.332
19/9/00	2.33	7.01	0.332

The DUL of 738 mm for a 1.9 m profile obtained after extended ponding at the DUL sample site was not reached in the sugarcane cropped area, even after the extended wet season (Figure 8.6). The extent of refill after irrigation was low and differed for each treatment with the drier treatments being drier at depth (Figure 8.7). The DUL was reached in the surface 60cm, but irrigation water applied had little effect on the lower depths especially in treatment 3. The average soil water after irrigation in treatment 1 was 73% of the PESW compared to 64% in treatment 2 and 59% in treatment 3. Chan (1981) found that the maximum storage capacity of the soil is rarely achieved under furrow irrigation of cracking clays. Deep drainage losses to the groundwater are minimal under normal irrigation practices in Cununurra clay at this site.

The profile soil water at Block 300-27-40 (Figure 8.8) shows that the amount of soil water stored at irrigation in a commercial crop scheduled for irrigation every 2 weeks varied through the season. From NMM readings at each depth, this vigorous plant crop extracted moisture to 160 cm and was drying out at depth as irrigation was not replacing all the soil water extracted below 60 cm (Figure 8.9). Rainfall prevented further measurements. The crop water use was low in early August in the young crop in cooler temperatures, but the crop began to use water at rates similar to pan evaporation in late August, September and October (Table 8.4).

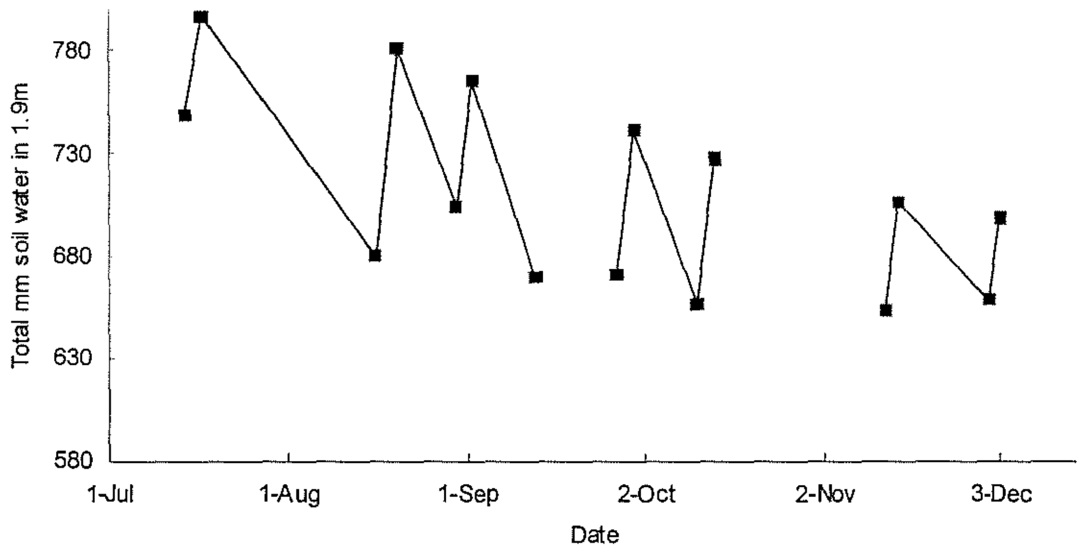


Figure 8.8. Profile soil water to 170 cm for Ord Sugar Mill Block 300-27-40 plant crop from neutron moisture readings taken the day before and two days after each irrigation 1999.

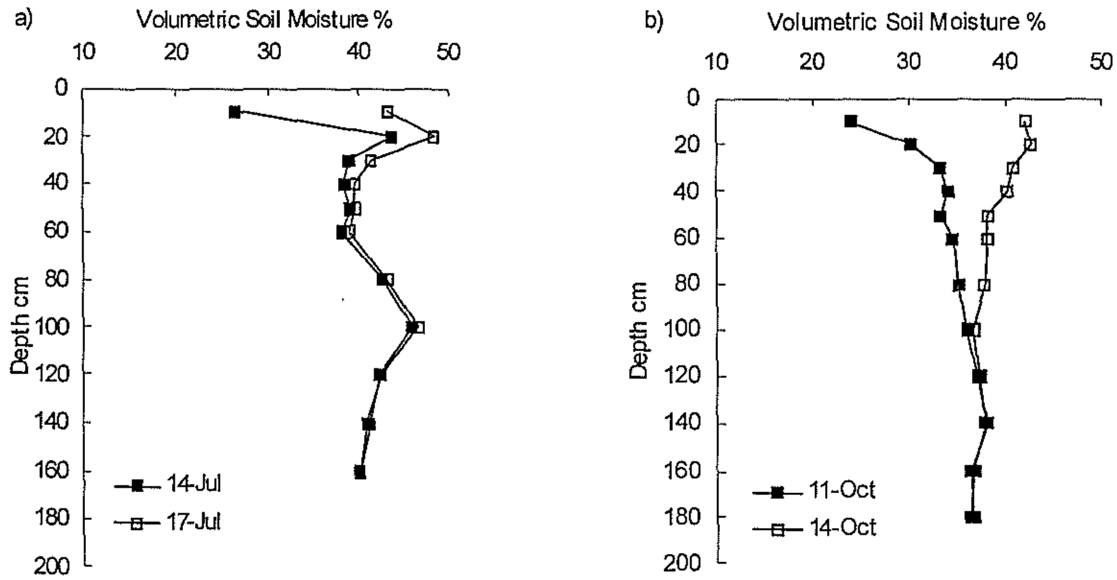


Figure 8.9. Sample profile soil water for Ord Sugar Mill Block 300-27-40 plant crop from neutron moisture readings taken the day before and two days after irrigation (a) 14 July 1999 and (b) 11 October 1999.

Table 8.4. Ord Sugar Mill Block 300-27-40 soil water use at each irrigation based on neutron moisture meter readings the day before and 2 days after each irrigation (24 access tubes averaged at each date)

Irrigation Date	Water use (mm/day) since 2 days after last irrigation	Average pan evaporation (mm/day) since 2 days after last irrigation	Ratio of water use / pan evaporation
16/8/99	3.3	6.10	0.541
30/8/99	6.3	6.67	0.945
13/9/99	7.5	6.84	1.097
27/9/99	6.8	7.24	0.939
11/10/99	7.4	7.64	0.969

Large differences between crop water use measured before and after the wet season occurred at the two sites. The ratio of water use to pan evaporation changed through the crop growth season, with high water use in a young growing crop in the pre-"wet" season and lower crop water use in a mature crop in the post-"wet" season before harvest.

Discussion

This study has provided information on the plant extractable soil water and pattern of water extraction with depth in the soil profile for a range of soil types in the ORIA. Four broad soil types across the Ivanhoe Plain were characterised. At the Central Ivanhoe site, 226 mm of water in 2m profile was available to the sugarcane plant. The plant extractable soil water in 2 m differed at the other sites with the Aquitaine, Northern Ivanhoe and the Southern Ivanhoe soils holding 187, 193 and 167 mm respectively. The depth of water extraction varied across sites with extraction occurring to 1.8 m at the Central and Northern Ivanhoe sites, 1.6 m at the Southern Ivanhoe site and to only 1 m at the Aquitaine site.

The four soil types are different in PESW and depth of extraction and so recommendations for scheduling irrigation across the ORIA using the soil water deficit as an indicator of when to irrigate is not accurate. Differences in PESW among soil types could lead to differences in the optimum soil water deficits at which to irrigate. The optimum soil water deficit at which to irrigate developed at one site can be converted to fraction of extractable soil water (FESW) remaining in the soil before irrigation. This figure can be transferable to other sites if the DUL and LL of these sites are known. For example the soil water deficit at the Central Ivanhoe site of 120mm is approximately equivalent to 0.5 FESW. The FESW of 0.5 at the Southern Ivanhoe site is equivalent to 84mm soil water deficit. Knowledge of the PESW across the ORIA will aid researchers to develop recommendations for irrigation scheduling across the ORIA. The standardised procedures used in this report will enable successful comparisons to be applied across further soils in the ORIA.

High rates of crop water use occurred in a sugarcane crop before the wet season, but low rates of water use relative to class A pan evaporation were observed after the wet season. This has implications for irrigation scheduling in the ORIA. Matching irrigations to crop water requirements will improve crop water use efficiency and reduce losses to the environment.

Knowledge of the extractable soil water and crop water requirements allows a better understanding of the response of sugarcane to irrigation schedules for different soil types.

The soil water characteristics information for these soil types in the ORIA is a prerequisite for the use of cropping system models to analyse the consequences of different irrigation regimes to develop strategies for best-practice irrigation management that maximise profitability and irrigation efficiency.

EnviroSCAN investigations

EnviroSCAN equipment was extensively used in an earlier SRDC funded project in the Ord for assessing drainage below the root zone (Nulsen and Sherrard, 1999). Firstly the equipment was calibrated for a range of soil types, as described in Sherrard *et al.*, (2002). An EnviroSCAN system was then installed in a first ratoon crop of sugar cane on Block 55 in 1996. The soil moisture level in this crop was monitored continuously until harvest in September 1997. After harvest, cultivation and fertiliser application, the system was re-installed in this same crop and changes in soil moisture further monitored until harvest in August 1998, to observe the possible occurrence of deep drainage. The same investigation also indicated reduced soil moisture extraction by the sugarcane crop as the wet season progressed.

In this project, EnviroSCAN equipment has largely been used for assessing crop water use. In Block 27 soil moisture levels were monitored for the 1999-2000 and 2000-2001 crops to record daily changes in soil moisture. These data were used to determine crop water use as well as to assess any drainage below the root zone. This allowed determination of water extraction on a daily basis and for the entire crop season (Figures 8.10 and 8.11). Due to confounding influences of wet season rainfall with saturated profiles, soil moisture extraction was assessed between periods of rainfall and extrapolated to estimate extraction on a daily basis.

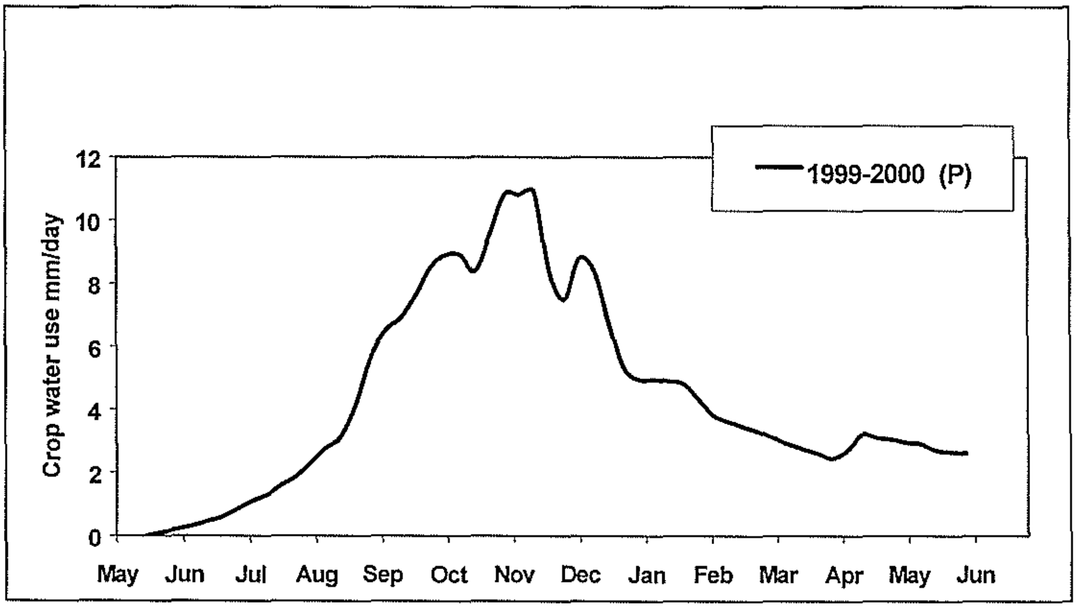


Figure 8.10. Soil moisture extraction by a plant crop of Q96 grown through the 1999-2000 season. The crop was planted in May 1999 and was harvested in June 2000.

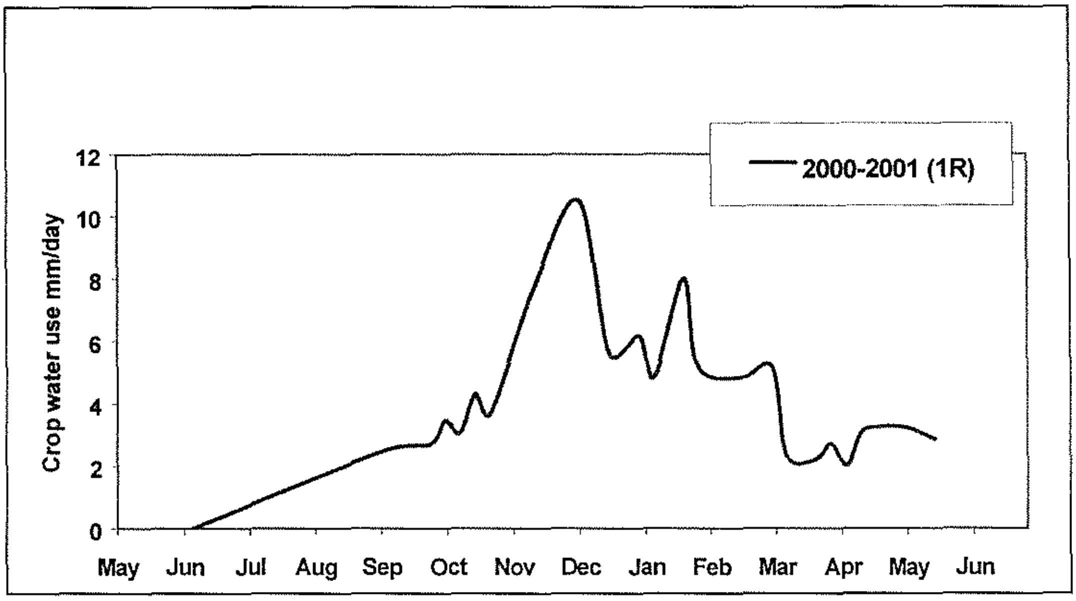


Figure 8.11. Soil moisture extraction by a first ratoon crop of Q96 grown through the 2000-2001 season. The crop was ratooned in June 2000 and was harvested in June 2001.

Water extraction peaked at 10.9mm/day for the 1999-2000 crop but was only slightly lower for the 2000-01 season. By integrating daily water use, total crop water use for the 1999-2000 and 2000-2001 crop cycles was estimated to be 17.3 and 13.5 ML/ha respectively. With crop yields of 183 and 140 tonnes cane/ha, 10.8 and 10.4t cane were produced per ML water used for the 1999-2000 and 2000-2001 crops respectively.

High rates of water use occurred for both crops prior to the wet season, dropping significantly as the wet season progressed and well before harvest. This has important implications for irrigation scheduling in the ORIA and for water allocation planning. Matching irrigation frequency and duration to crop water requirements will improve crop water use efficiency and reduce losses to the environment. This work also supports the finding of a growth slow-down observed in the sugarcane irrigation trial on Block 2B.

9. WEATHER CONDITIONS IN THE ORD FOR THE DURATION OF THE PROJECT

One of the main reasons for conducting this irrigation project in the Ord is that weather conditions are quite different from those in Queensland where most of the previous irrigation research has been conducted. It was important to compile credible current and long-term climate records in order to interpret the results of the field experiments and to extrapolate the results to different weather conditions that may occur in future years.

Two Campbell automatic weather stations were purchased using SRDC funds and were installed and calibrated. One was located at Cummings Brothers' farm, near the Frank Wise Research Station and the other at George Gardiner's farm at Packsaddle, in the southern part of the Ord River Irrigation area. The weather stations were installed in November 1996 and were working satisfactorily in March 1997. In addition to the two automatic weather stations, the manual weather station at the Frank Wise Research Institute was thoroughly checked, the radiation sensor recalibrated and the weather data obtained after 1988 checked for errors.

Rainfall

Annual rainfall in the Ord is extremely variable with less than 500 mm falling in some years and over 1400 mm falling in other years. Most of the rain falls from December to May. Rainfall in June to August is negligible (Figure 9.1).

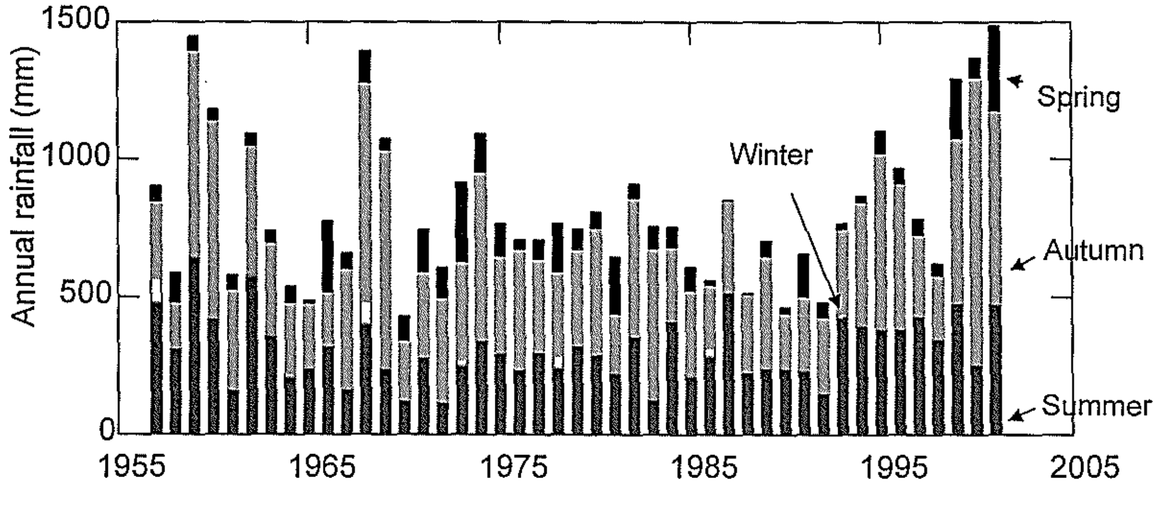


Figure 9.1. Contribution of rain in each season to total annual rainfall in the Ord.

Annual rainfall increased during the project from 621 mm in 1998, to 1286 mm in 1999, 1366 mm in 2000 and 1485 mm in 2001. Thus the project was conducted during some of the wettest years of the past 45 years. No other period in the past 45 years has experienced three such wet years in a row as 1999 to 2001.

The distribution of rainfall during the project is shown in Figure 9.2. A characteristic of the wet season in each year was its abrupt end whereas the start of the wet season was not clearly identified in the rainfall record. This means that irrigation scheduling during the start of the wet season will be complicated by rain but after the wet season the chances of disruption to any schedule will be low. Daily rainfall exceeded 100 mm on occasions and often exceeded 50 mm. Most of these high rainfalls would have been ineffective when soils were saturated from preceding frequent rain.

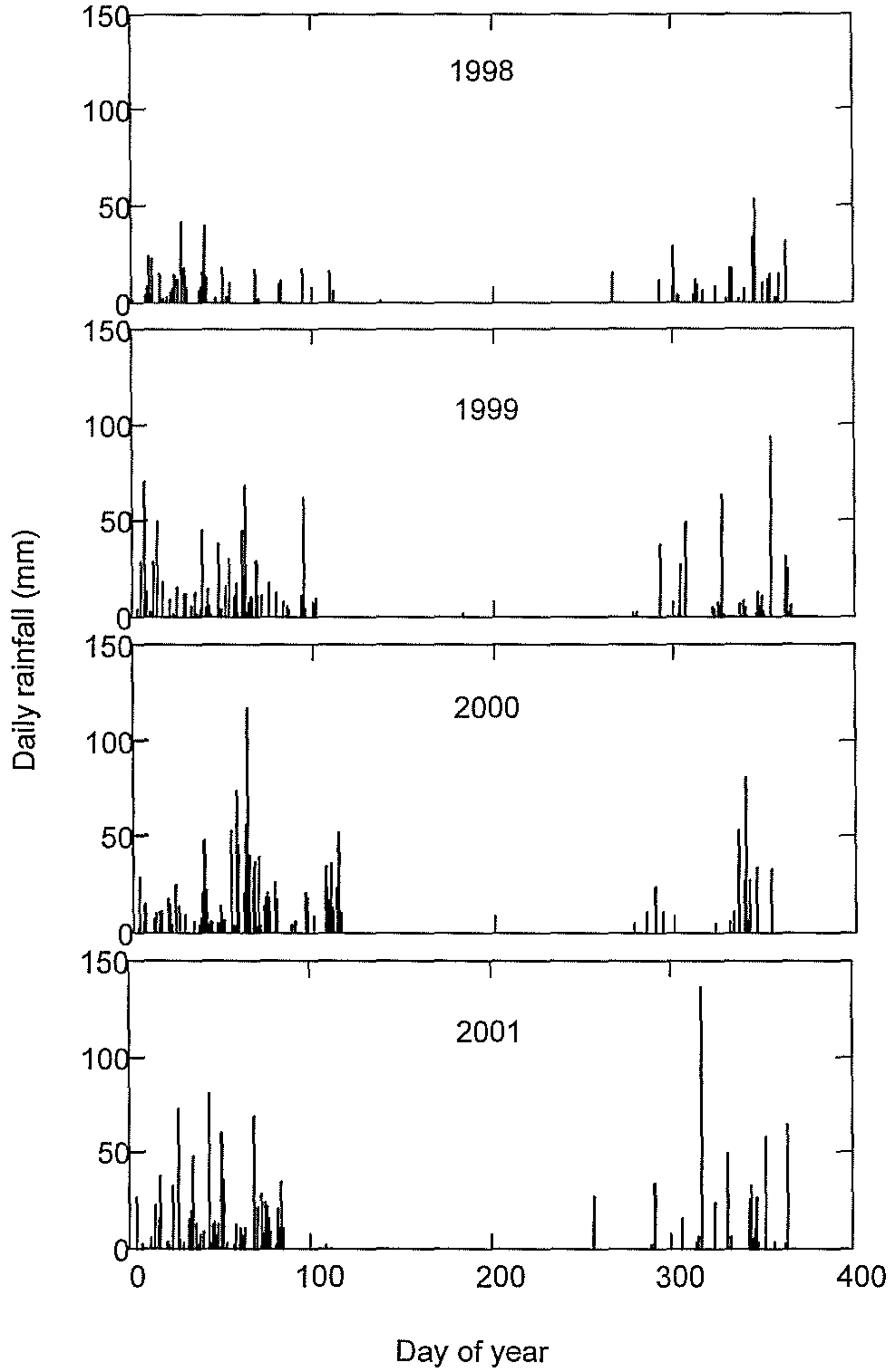


Figure 9.2. Daily rainfall measured at the Kimberley Research Station for 1998-2001

Radiation

Total annual radiation at the Kimberley Research Station is shown in Figure 9.3. The radiation during the life of the project was not particularly high compared to previous years as may be expected from the high rainfall during 1999 to 2001. Radiation was generally lowest in summer and highest in autumn. This may also be a distinguishing feature of the Ord climate in terms of crop growth. Low radiation combined with high temperature may have had unexpected effects on the crop such as significant losses of biomass due to respiration.

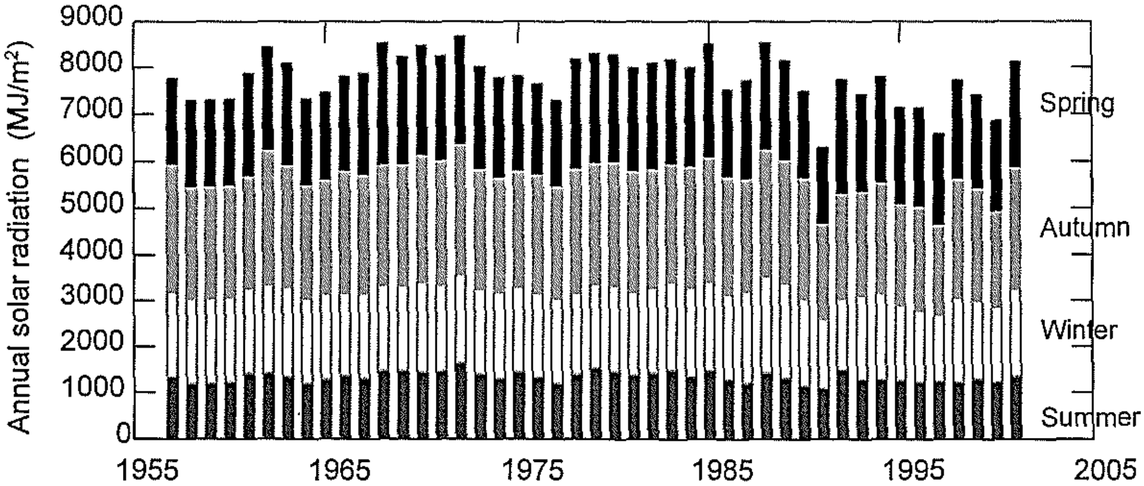


Figure 9.3. Contribution of solar radiation in each season to total annual radiation in the Ord.

Daily radiation for the years of the project are shown in Figure 9.4. The variation in radiation throughout the year is low compared to more southerly locations where cane is grown and it is noteworthy that winter or dry season radiation can be considerably greater than radiation in the wet season (Figure 9.3) even though peak radiation is higher in the wet season. There are two periods of peak radiation corresponding with two periods of maximum solar elevation between the equinoxes and summer solstice (Figure 9.4).

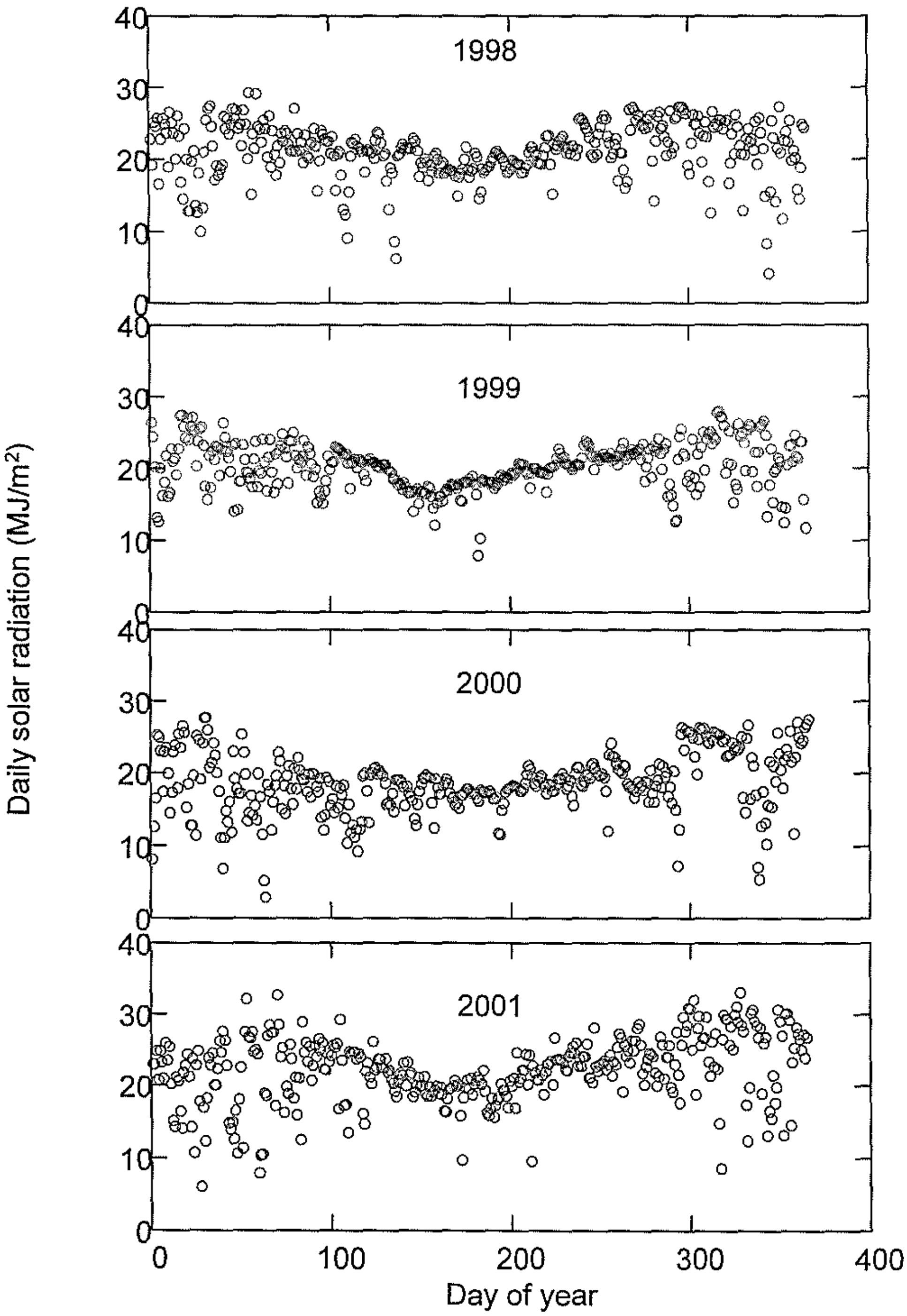


Figure 9.4. Daily solar radiation measured at the Kimberley Research Station for 1998 to 2001

Temperature

Mean winter or dry season temperature varied considerably from year to year exceeding 25°C in some years and dropping below 22 °C in other years (Figure 9.5). Mean summer (wet season) temperature has been remarkably consistent over the past 45 years ranging from 30 to 32 °C in all but 5 of the 45 years.

The variation in daily maximum temperature during the years of the project was not great (Figure 9.6). Maximum temperature varied between 30 and 40 °C for more than 80 % of days from 1998 to 2001. In about 5 % of days maximum temperature exceeded 40 °C. Not much is known about growth of sugarcane under these conditions. Extended periods of high temperature (> 35 °C) and occasional periods of extremely high temperature (>40°C) is what distinguishes the Ord region from other sugarcane regions in Australia. Minimum temperature varied more than maximum temperature over each of the years of the project (Figure 9.6). There were several days when minimum temperature was less than 10 °C and it was less than 20 °C for more than 35 % of days.

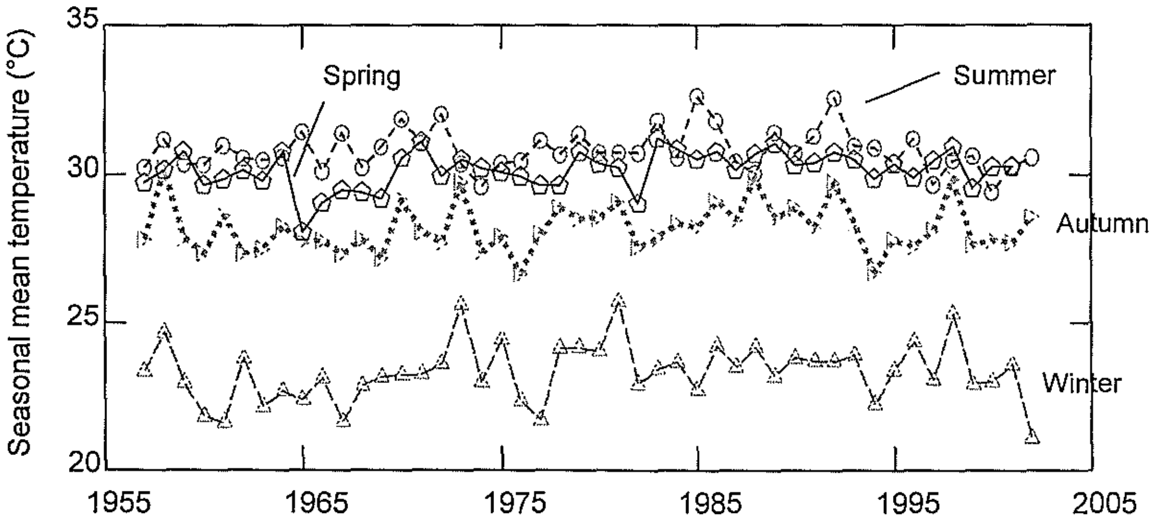


Figure 9.5. Mean temperature for each season over a 45 year period at Kimberley Research Station

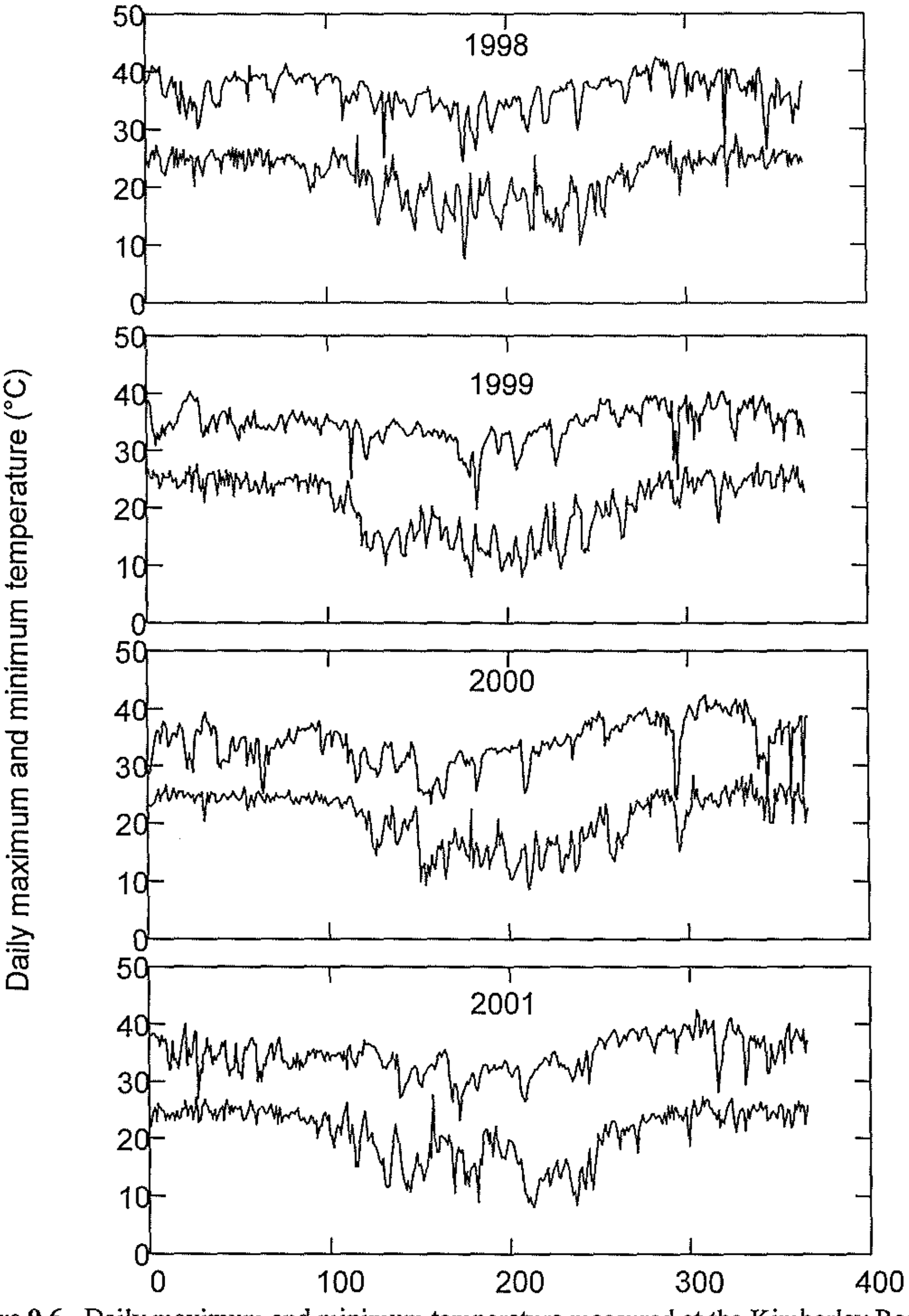


Figure 9.6. Daily maximum and minimum temperature measured at the Kimberley Research Station for 1998 to 2001

10. DEVELOPING IRRIGATION GUIDELINES USING THE APSIM SUGARCANE MODEL

Introduction

Sustainable irrigation management needs to take account of the productivity and profitability responses to irrigation timing and amount, and concurrently the need to maintain water resources and minimise losses and off-site environmental consequences.

In developing sustainable irrigation practice, the first step is to quantify the yield response to different irrigation schedules. Previously, research on sugarcane has been conducted in the Ord during the periods 1951-57, 1964-68 and 1975-82 (Cox and Chapman 1985). With ample low-priced irrigation water, little attention was paid to irrigation practice, but the few irrigation trials that were conducted gave no significant difference among irrigation treatments (Kingston *et al.* 1980). In the absence of data on Ord specific irrigation responses, Muchow and Keating (1998) used a modelling approach based on knowledge from other parts of the world to develop indicative estimates of irrigation water requirements and yield consequences for different management options for sugarcane production in the Ord. This analysis indicated an irrigation requirement up to 23 ML/ha, but the authors cautioned that field experimentation was a requirement under Ord conditions to confirm these estimates.

The necessary field experimentation was carried out as reported in section 7 of this report. From these experiments alone, it is difficult to develop irrigation scheduling guidelines for the Ord sugar industry. However, these experiments do allow the testing of the modelling approach and indicative estimates of irrigation experiments as provided by Muchow and Keating (1998).

To proceed it was necessary to: (i) understand the processes of yield accumulation in these experimental crops in response to water supply; (ii) encapsulate this understanding into a sugarcane simulation model; and (iii) use the simulation model to develop irrigation guidelines. Accordingly, the aim of this section is firstly to test the APSIM Sugarcane model (Keating et al. 1999) against observations of yield accumulation and soil water extraction from Field 2A experiments reported in section 7. Secondly we allowed for a process of calibration, if this was required, to tailor the model for Ord conditions. The third aim was to link long-term climatic data and soil water characteristics of the main soil type (Cununurra Clay) with APSIM Sugarcane to develop indicative estimates of irrigation water requirement and yield consequences for different irrigation scheduling options for sugarcane production in the Ord.

Materials and Methods

Field and model analysis of yield accumulation and soil water extraction

Yield accumulation in two crop cycles was measured for crops grown on Cununurra Clay (Bridge and Muchow 1982) at the Frank Wise Institute Kununurra (lat. 15.65° S, long. 128.72° E). A plant (P) crop was planted on 6 May 1998 and the 1st ratoon (R) crop was started on 4 August 1999 (see Section 7). Three irrigation treatments with 3 replications were applied to each crop as outlined in Section 7 and also by Muchow *et al.* (2001). The P crop was irrigated after 120 mm of pan evaporation until canopy closure on 18/9/98, and thereafter irrigated after either 60,120 or 180 mm of pan evaporation. The ratoon crop was irrigated after 120 mm of pan evaporation until canopy closure on 15/11/99, and thereafter irrigated after either a soil water deficit of 79, 123 or 191 mm. The crops were furrow irrigated. For the P crop, a drying-off period prior to harvest of 26 days was imposed for the 60mm pan evaporation treatment, 27 days for the 120mm pan evaporation treatment and 28 days for the 180mm pan evaporation treatment. For the R crop, a drying-off period of 28 days was imposed on all treatments prior to harvest.

The crops were hand-sampled with harvesting 18 m^2 of crop at intervals as shown in Figure 10.1. Crop biomass and stalk sucrose were determined using the procedures outlined in Muchow *et al.* (1993). These data are from clean stalk samples and differ from the commercial yields obtained by mechanically harvesting large plots as shown in Muchow *et al.* (2001). Soil water extraction was measured throughout crop growth using a Neutron Moisture Meter, as outlined by Muchow *et al.* (2001).

Simulation analysis of irrigation strategies

The APSIM-Sugarcane model is designed to simulate a uniform block of cane and predict on an area basis, crop biomass, sucrose yield, crop water use and irrigation requirement, assuming 100% irrigation application efficiency (Keating *et al.* 1999). The model operates on a daily time-step and is 'driven' by climatic factors including rainfall, temperature and solar radiation; soil factors such as depth, water holding capacity and nitrogen status; management factors such as planting/ratooning date, fertiliser and irrigation; and genetic factors. The soil water module for APSIM is described in Probert *et al.* (1998). The model has not been tested previously in the Ord environment because of the lack of complete datasets where crop, soil, climate and management data were collected. The analysis here provides the first test of APSIM-Sugarcane in the Ord environment.

All simulations were conducted for Cununurra Clay having soil water characteristics as shown in Table 10.1. Muchow *et al.* (2001) observed that sugarcane extracted water to 1.9 m on this soil type, and the total plant extractable soil water (PESW) was 225 mm. Plant extractable soil water is defined as the water held at tensions between the crop lower limit and the drained upper limit, parameters that are determined empirically using methods described by Dalgliesh and Foale (1998). Nutrition was assumed to be non-limiting. Stage 1 soil evaporation coefficient was set to 6 mm, stage 2 soil evaporation was set to 3.5 mm and curve number was set to 82 (Muchow and Keating 1998). The effectiveness of the canopy on reducing curve number and the maximum reduction in curve number due to cover were set to zero. The crop transpiration efficiency was set to 0.01 and the coefficient for the vapour pressure deficit was changed from 0.75 to 0.70 to represent Ord conditions based on the analysis of B.A. Keating and N.I. Huth (unpublished data).

Table 10.1. Characteristics of Cununurra Clay soil from Muchow *et al.* (2001) used in APSIM-Sugarcane simulation runs

Depth (mm)	Bulk Density	Drained upper limit	Lower limit
0-150	1.502	0.392	0.170
150-250	1.497	0.368	0.234
250-350	1.513	0.375	0.269
350-450	1.509	0.380	0.274
450-550	1.466	0.379	0.267
550-650	1.510	0.392	0.277
650-750	1.519	0.402	0.283
750-850	1.513	0.393	0.290
850-950	1.548	0.403	0.303
950-1050	1.495	0.393	0.301
1050-1150	1.435	0.379	0.294
1150-1250	1.462	0.397	0.303

1250-1350	1.512	0.415	0.304
1350-1450	1.539	0.421	0.270
1450-1550	1.562	0.412	0.251
1550-1650	1.627	0.398	0.266
1650-1750	1.708	0.372	0.267
1750-1850	1.708	0.345	0.277
1850-1900	1.721	0.338	0.300

The model analysis approach requires quality climatic data, soil water characteristics and confidence in the ability of the model to simulate responses to specified inputs. For the model analysis of the two experiments of Muchow *et al.* (2001), daily radiation, maximum and minimum temperature and rainfall data were sourced from an automatic weather station sited 0.5 km from the experiments. Using these climate data and the observed soil water characteristics of the experimental site (Table 10.1), simulations were conducted using the observed crop start and finish dates and the observed dates of furrow irrigation. The extent of refill of the soil profile at each irrigation in the simulations was based on observed soil water profiles after irrigation. For the P crop, the profile was filled to 80% of total plant extractable soil water (PESW) at irrigation. For the R crop, the profile was filled to 78% of total PESW for the 79mm treatment, 73% for the 123mm treatment and 70% for the 191mm treatment. Those differences reflect limitations in rates of water entry and re-distribution in the heavy clay soils of the region.

In developing irrigation scheduling guidelines, long-term climatic data (daily solar radiation, maximum and minimum temperatures, rainfall and Class A pan evaporation) were sourced from the Frank Wise Institute for the period 1957 to 2000. For the long-term simulations, APSIM Sugarcane was configured for a ratoon crop starting either on 1 June, 1 August or 1 October and harvested at 12 months of age. The initial soil water was set to a FESW of 0.1. Irrigation was scheduled the day after ratooning and second irrigation was scheduled at 30 days after ratooning in the absence of rainfall. Thereafter, irrigation was scheduled at different soil water deficit as shown in Table 10.2 with a drying-off period prior to harvest of 30 days. Irrigation was assumed to fill the profile to 75% of total PESW and the amount of irrigation applied assumes an application efficiency of 100%.

Table 10.2. Number of irrigations, irrigation amount (at 100% application efficiency) and sucrose yield for irrigation at different soil water deficits with a 30 day drying off period, averaged for years 1957-2000 for ratoon crops started on 1 June, 1 August and 1 October and harvested at 12 months. The PESW was 225 mm and irrigation was scheduled at Fraction Extractable Soil Water (FESW) ranging from 0.6 to 0.1.

Irrigation FESW	Strategy Deficit (mm)	Variable	Crop Start		
			1 June	1 August	1 October
0.6	90	Nº irrigations	36.9	34.2	30.7
0.5	112.5	"	23.0	21.1	19.0
0.4	135	"	16.7	15.4	13.7
0.3	157.5	"	13.0	11.9	10.9
0.2	180	"	10.1	9.3	8.8
0.1	202.5	"	7.3	6.9	6.7
0.6	90	Irrigation (mm)	1499	1384	1222
0.5	112.5	"	1448	1324	1180
0.4	135	"	1398	1275	1132
0.3	157.5	"	1319	1201	1098
0.2	180	"	1192	1088	1025
0.1	202.5	"	948	891	878

0.6	90	Sucrose yield (t/ha)	20.6	20.3	20.1
0.5	112.5	"	20.5	20.2	20.0
0.4	135	"	20.2	20.0	19.8
0.3	157.5	"	19.5	19.4	19.6
0.2	180	"	18.1	18.4	18.8
0.1	202.5	"	15.5	16.4	16.7

Results and Discussion

Yield accumulation and soil water extraction

The accumulation of aboveground biomass over time is shown for the P and R crop in Figure 10.1. There was a marked reduction in growth rate after sampling 2 (224 days after planting or 16 December 1998 and 160 days after ratooning or 1 January 2000). For comparison, a plant crop grown in the Burdekin under fully irrigated conditions in the 1991-92 season and similarly sampled (Muchow *et al.* 1994) is shown in Figure 10.1. This Burdekin crop showed a linear growth rate from 214 to 353 days after planting of 41.3 g m^{-2} d^{-1}. For the P crop grown in the Ord, the growth rate between sampling 1 and 2 (153 to 224 days after planting) was 30.4 g m^{-2} d^{-1}, and thereafter the average growth rate was 10.1 g m^{-2} d^{-1}. A similar trend was evident for the R crop in the Ord (Figure 10.1). The growth rate between sampling 1 and 2 (97 to 160 days after ratooning) was 28.5 g m^{-2} d^{-1}, and thereafter the average growth rate was 4.9 g m^{-2} d^{-1}.

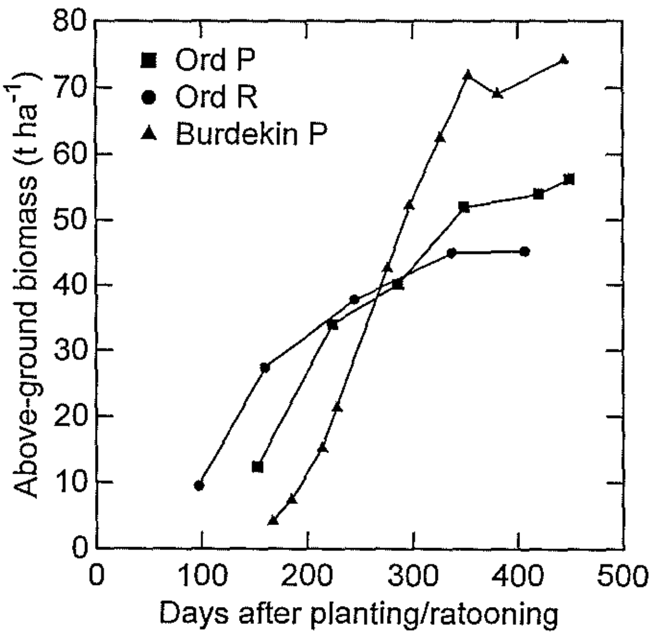


Figure 10.1. Accumulation of aboveground biomass (dry weight) over time for the plant (Ord P) and ratoon (Ord R) crop grown in 1998-99 and 1999-00 respectively in the Ord. Data for the Ord P crop are the mean of the 60mm and 120mm pan evaporation treatments of Muchow *et al.* (2001). Data for the Ord R crop are the mean of the 79mm and 123mm soil water deficit treatments of Muchow *et al.* (2001). A plant crop grown in the Burdekin (Burdekin P) under fully irrigated conditions in the 1991-92 season and similarly sampled as reported by Muchow *et al.* (1994) is also shown.

The factors contributing to this growth reduction from mid-wet season in the Ord are not known. However, the crops did lodge during this period, and this may be a cause. A slow-down in growth has been observed for large lodged crops by Muchow *et al.* (1995), Robertson *et al.* (1996) and Muchow *et al.* (1997a). APSIM-Sugarcane estimates of crop biomass in the absence of lodging (broken line) tended to be much higher than the observed crop biomass, particularly during later growth (Figure 10.2). This is in contrast to the many environments where APSIM Sugarcane has been shown to reliably simulate field performance (Muchow *et al.* 1997b; Lisson *et al.* 2000).

The simulation model of Keating *et al.* (1999), as used in the indicative analyses of irrigation requirements in the Ord by Muchow and Keating (1998), was not configured for any growth reduction that may possibly be attributed to lodging. Based on the analysis of radiation use efficiency of these crops (Muchow *et al.* unpublished data) and the observations of Singh *et al.* (2000) for lodged crops, the model was re-configured to reduce radiation use efficiency (RUE) to 1.0 g/MJ after above ground biomass reached 30 t/ha, since this was approximately the above-ground biomass at sampling 2 (Figure 10.1). With these modifications, APSIM Sugarcane simulated less growth during the later growth stages (solid line, Figure 10.2) and closely mirrored the observed growth patterns in the field grown P and R crops (Fig. 2). Pooling all data, the simulations using the modified APSIM-Sugarcane model were in close agreement with observed crop biomass over the range of 10 to 60 t/ha (Figure 10.3a). There was a slightly lower correlation in the simulation of sucrose yield, but still more than 90% of the variation was accounted for (Figure 10.3b). The pattern of soil water extraction also closely followed the observed data, especially for the plant crop (Figure 10.4).

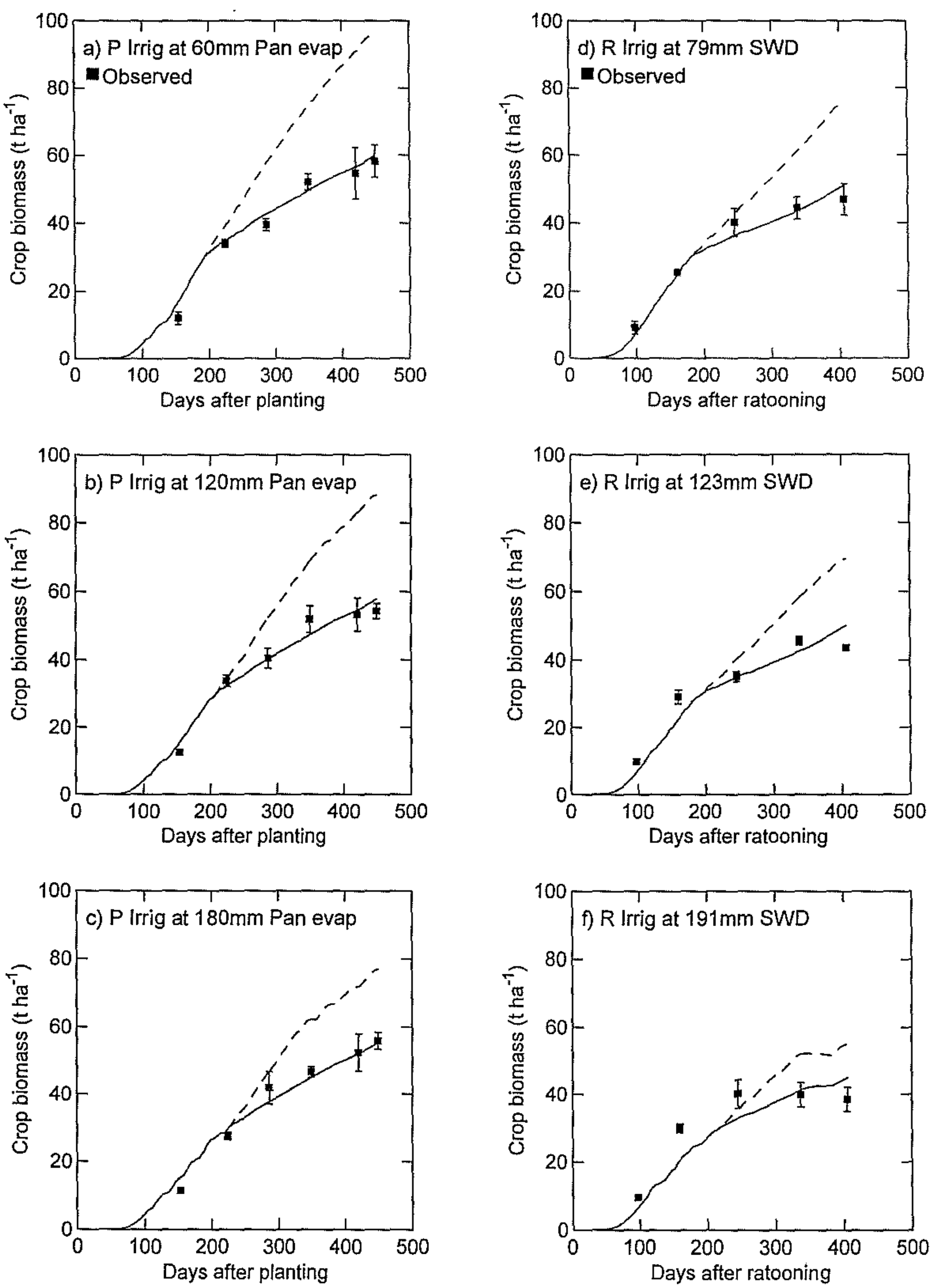


Figure 10.2. Observed and simulated crop biomass (dry weight) over time for the P crop for irrigation after a) 60, b) 120 and c) 180 mm of pan evaporation and for the R crop for irrigation at a soil water deficit of d) 79, e) 123 and f) 191 mm. The simulated crop growth (broken line), using the original APSIM Sugarcane model of Keating et al. (1999), and the simulated crop growth (solid line), using the model configured with the growth slow-down phenomenon, are also shown.

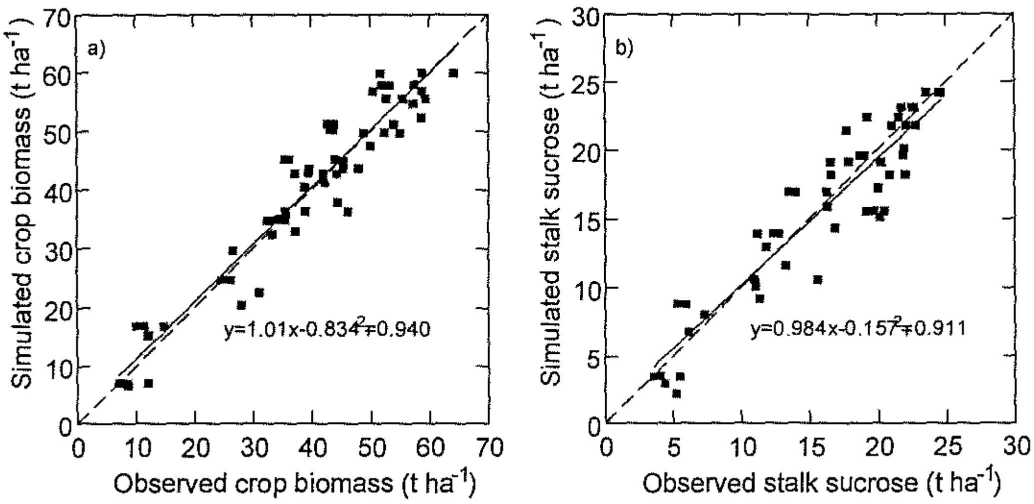


Figure 10.3. Simulated (using the model configured with the growth slow-down phenomenon) vs observed a) crop biomass (dry weight) and b) stalk sucrose for all P crop treatments and all R crop treatments.

By using the original model of Keating *et al.* (1999) and the modified model, the significance of a lower RUE during later growth can be assessed. The growth "slow-down" phenomenon substantially impacted on yield. For example, at the final sampling at 449 days after planting of the P crop irrigated after 60 mm of pan evaporation, the observed crop biomass was 58.2 t/ha, and the simulated crop biomass configured for growth slow-down was 59.9 t/ha. Yet the simulated crop biomass using the original model without growth slow-down was 96.0 t/ha (Fig. 2). The corresponding observed sucrose yield was 24.2 t/ha compared with the simulated sucrose yield with growth slow-down of 24.1 t/ha . However, the potential sucrose yield for the 15-month-old crop with no growth slow-down was 40.5 t/ha. The growth slow-down phenomenon also impacts on crop water use, with the irrigation requirement (at 100% application efficiency) for this crop decreasing from 2045 to 1515 mm.

The modified model was used in the subsequent simulations presented in this paper as it closely describes the observed crop growth, yield and water use of the range of irrigation treatments over two seasons. Further field investigation of the growth slow-down phenomenon for different seasonal conditions and crop start (ratooning) dates is required, together with studies of how best to represent this phenomenon in cropping models. In the meantime, the simulation analyses that follow provide the current best-bet estimates of sugarcane crop responses to different irrigation schedules.

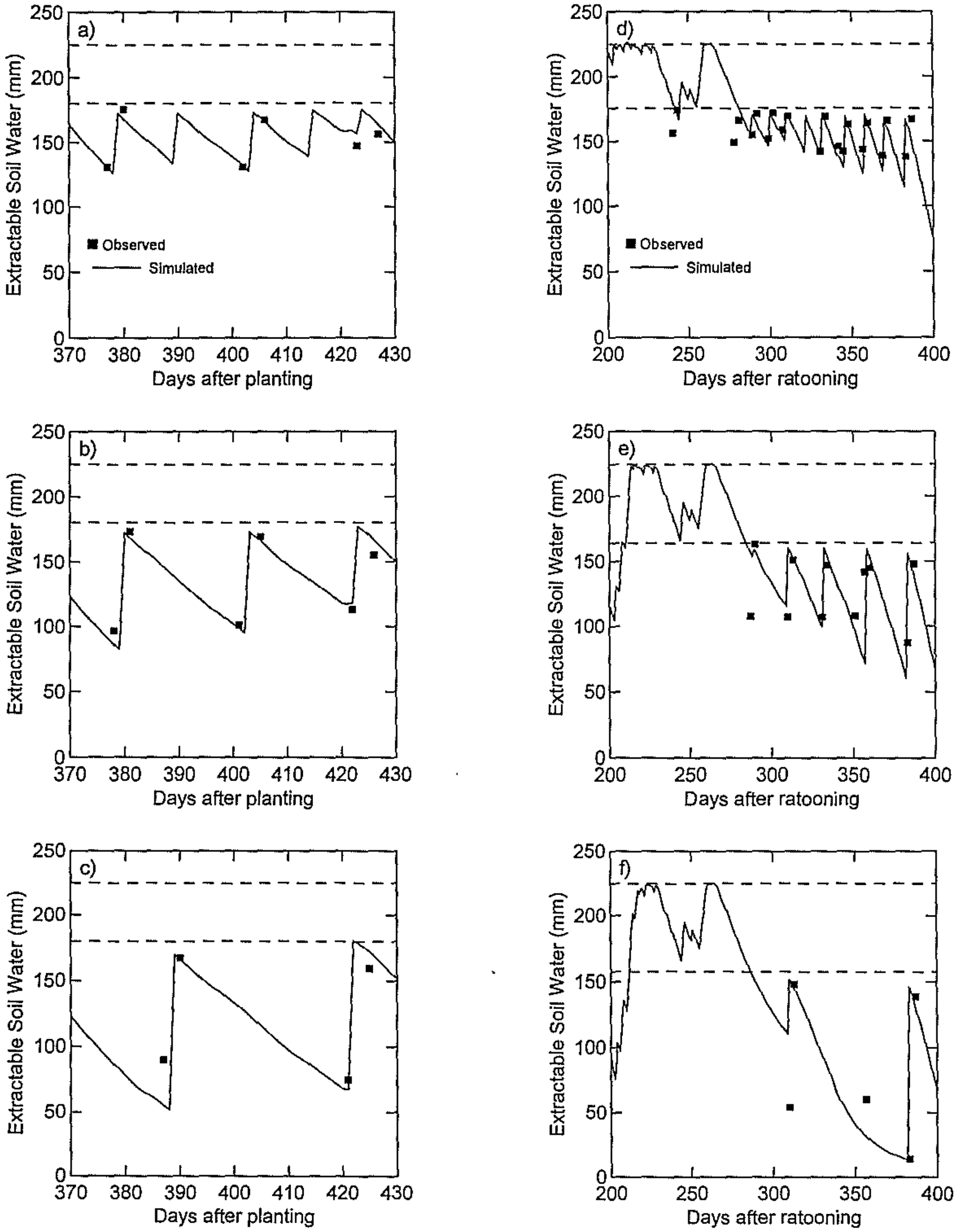


Figure 10.4. Soil water extraction over time for the P crop for irrigation after a) 60mm, b) 120mm and c) 180 mm of pan evaporation and for the R crop for irrigation after d) 79mm, e) 123mm and f) 191mm soil water deficit. The PESW of 225 mm and the refill points at irrigation (80% for a), b) and c), 78% for d), 73% for e) and 70% for f)) are shown by the parallel broken lines.

Simulated yield and irrigation response to soil water deficit

Crops were simulated with the modified APSIM Sugarcane model starting in the 1957-58 season and finishing in the 1999-2000 season. The average sucrose yield response to irrigation at different soil water deficits for ratoon crops started on 1 June, 1 August and 1 October is shown in Table 2. As expected the number of irrigations decrease markedly when the irrigation interval is extended from irrigating at a soil water deficit of 90 mm to 135 mm; thereafter the number of irrigations was not markedly changed for irrigation at greater soil water deficits. The amount of irrigation applied (assuming 100% irrigation application efficiency) progressively decreased with greater soil water deficit at irrigation (Table 10.2). Application efficiency would be lower with more frequent irrigation as greater soil water deficits at irrigation result in more soil cracking and better infiltration (Muchow and Wood 1981). Consequently, the actual amounts of irrigation applied in field practice would be greater than the data shown in Table 10.2, especially for the more frequent irrigation schedules. Crops starting on 1 June required most irrigation while those starting on 1 October required least irrigation.

Muchow and Keating (1998) used historical climate for 1960-1985 and for a crop ratooned on 1 September and irrigated at FESW of 0.5, estimated an irrigation requirement of 2269 mm applied in 22 irrigations and a potential sucrose yield of 29.0 t/ha. These results did not account for the growth reductions being observed during the wet season in large lodged crops in the Ord. In contrast in the current analysis, August and October ratoons irrigated at FESW of 0.5 respectively had an irrigation requirement of 1324 to 1180 mm applied in 21-19 irrigations, associated with simulated sucrose yields of 20.2 to 20.0 t/ha (Table 10.2). The growth – slow down phenomenon reduces the irrigation requirement by approximately 40% and reduces sucrose yield by up to 30%.

The sucrose yield response to irrigation schedule shows relatively minor effects on yield until the soil water deficit at irrigation is extended beyond 135 mm (Table 10.2). In contrast to the number and amount of irrigation, sucrose yield was least sensitive to crop start date. The most profitable irrigation schedule will be dependent on the cost of water as determined by amount applied, labour costs as influenced by the number of irrigations and the price for sugar. However, data as shown in Table 10.2 are valuable for examining the tradeoffs with different irrigation schedules. Given the need for more field-testing of the model, we would advocate a conservative approach at this stage and subsequent analyses are present for irrigation scheduling at a soil water deficit of 135 mm.

Year to year variability in yield and irrigation requirement

The year-to-year variation in irrigation requirement when irrigation was scheduled at a soil water deficit of 135 mm for the last 10 years is shown in Table 10.3. Rainfall during the wet season is highly variable from year to year. In fact for the period 1957 to 2000, the driest (1997-98) and wettest (1999-2000) year occurred in recent times. For the driest year with 473 mm of rainfall, 19 irrigations were required to apply 1573 mm of irrigation whereas in the wettest year with 1443 mm of rainfall, 9 irrigations were required to apply 760 mm of irrigation. More of the rainfall was effective in the driest year. Sucrose yield was higher in 1997-98 than in 1999-2000, most likely associated with higher solar radiation from less cloud cover. However, over the historical record, there is little association between sucrose yield and amount of rainfall.

Table 10.3. Yearly variation in rainfall, effective rainfall (%), number and amount of irrigation and sucrose yield for irrigation at 0.4 FESW (135 mm soil water deficit) with a 30 day drying-off period for 12 month ratoon crops started on 1 August for years 1990-1991 to 1999 – 2000

Season	Rainfall (mm)	Effective rainfall (%)	Number of Irrigations	Amount of Irrigation (mm)	Sucrose yield (t/ha)
1990-91	596	70.2	17	1407	19.5
1991-92	578	77.1	18	1490	20.3
1992-93	783	59.1	17	1401	19.9
1993-94	722	58.2	16	1318	19.7
1994-95	1143	61.3	12	996	20.3
1995-96	826	73.6	15	1236	20.5
1996-97	1061	56.1	15	1239	20.1
1997-98	473	82.6	19	1573	20.4
1998-99	1145	66.6	12	1003	19.2
1999-2000	1443	51.0	9	760	17.1

Table 10.3 highlights the importance of distribution of rainfall given that the number of irrigations is not closely related with rainfall. For example, more irrigations were required in 1992-93 with a rainfall of 783 mm than in 1993-94 when rainfall was less at 722 mm. This resulted in a difference in irrigation requirement from 1401 to 1318 mm. The irrigation requirement also varied with crop start date. For the driest year (1997-98) a 1 June start date required 20 irrigations applying 1655 mm of irrigation, whereas a 1 October start date required 18 irrigations applying 1500 mm of irrigation (data not shown). Hence, the greatest source of variation in irrigation requirement is year-to-year variation rather than different cropping cycles.

Comparison of the irrigation requirement for 1995/96 (Table 10.3) with the benchmarking survey of actual practice (Wood *et al.* 1998) shows that considerable savings can be made in irrigation in the ORIA. The simulations in Table 10.3 indicate a requirement for 15 irrigations and 1236 mm of irrigation in 1995-96. In the survey, the average number of irrigations was 27 and the annual irrigation applied at 70% application efficiency was 3250 mm, which translates into a requirement of 2175 mm at 100% application efficiency. Whilst there is considerable variation in the survey benchmark data of Wood *et al.* (1998) and not all crops were initiated in August and were harvested at 12 months of age, nevertheless the difference in irrigation requirement is large. This indicates considerable potential for more efficient use of water resources for sugarcane production in the ORIA.

Monthly irrigation scheduling guidelines

The scheduling of irrigation throughout the crop cycle will depend on the extent of canopy development, the rate of crop growth, the potential evaporative demand and rainfall patterns. To guide irrigation practice on-farm, an analysis was undertaken on a monthly basis to determine the number of irrigations required per month and the trigger point for each irrigation based on Class A pan evaporation (Table 10.4). The analysis was undertaken using a conservative irrigation strategy of irrigating after a soil water deficit of 135 mm for the driest season (1997-98) and the wettest season (1999-2000) where the total number of irrigations required ranged from 19 to 9 (Table 10.3). Given an irrigation schedule that triggers an irrigation at FESW of 0.4 and refills the profile to 75% of FESW, this means that the next irrigation would be triggered after 78.8 mm of crop water use. The crop water on a daily basis is computed as the daily Class A pan evaporation times the ratio of crop water use to Class A pan evaporation as shown in Table 10.4.

Table 10.4. Monthly irrigation guidelines for a low rainfall (1997-1998) and a high rainfall (1999-2000) growing season. Crops are ratoon crops started on 1 June, I August, 1 October and grown for 12 months where irrigation is scheduled at 0.4 FESW (135 mm soil water deficit) with a 30 day drying-off period. The number of irrigations and the ratio of crop water use to pan evaporation (pan factor ET/Ep) are shown.

Month	1997-98 Season Number of Irrigations			1999-00 Season Number of Irrigations			1997-98 Season Pan factor			1999-00 Season Pan factor		
	1 Jun	1 Aug	1 Oct	1 Jun	1 Aug	1 Oct	1 Jun	1 Aug	1 Oct	1 Jun	1 Aug	1 Oct
Jun	1			1			0.14			0.14		
Jul	1			1			0.22			0.20		
Aug	2	2		1	2		0.76	0.14		0.54	0.12	
Sep	3	0		4	0		1.29	0.22		1.27	0.21	
Oct	4	3	2	2	1	1	1.31	0.81	0.13	1.32	0.82	0.34
Nov	4	3	0	3	3	0	1.18	1.29	0.34	1.39	1.39	0.32
Dec	0	2	1	0	1	0	0.93	1.43	1.22	0.82	1.30	0.85
Jan	1	1	2	0	1	1	0.81	1.08	1.31	0.80	1.17	1.27
Feb	0	1	2	0	0	0	0.80	0.88	1.40	0.73	0.79	1.28
Mar	3	2	2	0	0	0	0.75	0.80	0.99	0.67	0.71	1.19
Apr	1	2	2	0	0	0	0.67	0.69	0.76	0.50	0.51	0.62
May	0	2	2	0	0	0	0.46	0.70	0.74	0.46	0.46	0.51
Jun		1	2		1	1		0.65	0.66		0.46	0.51
Jul		0	1		0	2		0.55	0.60		0.61	0.66
Aug			2			1			0.74			0.76
Sep			0			0			0.50			0.45

The frequency of irrigation is dependent on the evaporative demand, the occurrence of rainfall, and the crop water use. In general, the pan factors (ratio of crop water use to Class A pan evaporation) increases during early growth with canopy development towards a maximum value in excess of 1.0 and then decreases during later growth associated with the growth slow-down phenomenon (Table 10.4). However, the actual number of irrigations each month of a given ratooning date varied with year associated with differences in the occurrence of rainfall and evaporative demand (Table 10.4). In general terms, the data in Table 4 show that more frequent irrigation is required in the September to November period, but moderated according to the extent of canopy development and rainfall events.

In practical terms, the data in Table 10.4 can be used as a guide to irrigation scheduling using the monthly pan factors for different ratooning dates and the observed Class A pan evaporation. When the pan factor times the Class A pan evaporation accumulates to 78.8 mm, then an irrigation would be triggered. However, these data only relate to one soil type (PESW of 225 and 75% refill at irrigation) and further research is required to test the wider applicability of these findings.

General Discussion

Sustainable irrigation schedules need to maximise profitability and not necessarily productivity, and minimise water losses and accessions to the groundwater. This modelling analysis has shown that there is a trade-off between sucrose yield and irrigation water requirement when varying the frequency of irrigation. Where irrigation frequency is decreased from irrigation schedules that allow little soil water depletion to those that allow about two-thirds of the plant extractable soil water (PESW) to be depleted before irrigation, there are considerable savings in the number of irrigations and thus labour requirements with relatively little penalty on yield. Water losses are also reduced in practice, as the irrigation application efficiency for furrow irrigated Cununurra Clay increases as the irrigation interval is lengthened (Muchow and Wood 1981). This will have important environmental benefits with reduced deep drainage and accessions to the groundwater, and reduced runoff. As the irrigation frequency is further reduced with irrigation after more than two-thirds of the PESW is depleted, dramatic reductions in sucrose yield and crop water use are predicted. The most profitable irrigation schedule will depend on the price of sucrose and the cost of irrigation relative to other growing costs.

This research has made considerable progress in defining irrigation requirements and irrigation scheduling guidelines for the Ord Sugar Industry. Indeed, the current analysis is indicative of a lower irrigation requirement and less frequent irrigation schedules than the earlier analysis of Muchow and Keating (1998). The main reason for this difference is the observed growth slow-down phenomenon observed in two experimental crops in the Ord in 1998-99 and 1999-2000. More research is required to explain those observations and test their wider applicability as a basis for developing robust irrigation scheduling strategies for a profitable and sustainable Ord Sugar Industry.

11. IRRIGATION WATER APPLICATION EFFICIENCY

Introduction

The management of rising ground water levels in the ORIA is recognised as essential in ensuring the sustainability of irrigated agriculture in the region. Low irrigation water application efficiencies in the predominantly furrow irrigated bays are contributing to rising groundwater through runoff and deep drainage. This has become more evident with the changes in land-use in the ORIA with the re-introduction of sugar cane as a long season crop.

The cause of the rising water tables is often associated with deep drainage. Whether that occurs in the bays, tail drains, supply channels or in the drains is not clear. Rose *et al.* (1979) observed long term changes in salinity profiles under rice bays and furrow irrigated sugar cane/safflower bays over a 9 year period in the ORIA (1954 – 1963) indicating a drainage flux under the rice bays of 80 mm/year.

Gordon and Gardner (1997) did some work based on chloride contents in several profiles and assuming a steady state, predictions of deep drainage were made. The magnitude of the deep drainage varied with soil type, water salinity and applied amount of irrigation. The lowest predicted value was 13 mm/year and the highest was 69 mm/year for an irrigation salinity of 0.2 dS/m.

Kinhill Engineering Consultants Ltd. (1999) in a feasibility study for Ord Stage 2 calculated annual accessions to groundwater using a water balance model (LEACHM). That varied from 56 mm/year to 119 mm/year depending on soil type and hydraulic conductivity associated with the soil profile. The maximum accession always occurred immediately after the wet-season during March when the profile was completely saturated with very little deep drainage occurring for the rest of the year. The latter has been frequently observed during the course of this project using permanently installed soil moisture measuring equipment.

Banyard (1983) found significant drainage losses after some intensive studies by the Water and Rivers Commission through blocking-off major drains and supply channels. Measuring the infiltration it was found that the seepage losses in the channels varied from 3 mm to 60 mm per day over the water surface and in the drains from 8 mm to 1000 mm per day. This equated to about 19 to 33 mm per year across the irrigable area in the ORIA from the channel infrastructure only.

It appears that the rising water tables have several causes and inadequate on-farm application efficiency (AE) is one of them. Improving the AE by minimising the losses through the tail drain and deep drainage would therefore be a positive contribution to the management of the water tables.

The assessments of opportunities to improve AE was aided by a surface irrigation model (SIRMOD) (Walker, 1993) which has been tested extensively both overseas and in Australia mainly in non-swelling soils. In the ORIA during the course of the project irrigation AE's were investigated for a number of furrow irrigated bays of sugar cane on Cununurra clay soils. This section presents data collected on those bays, the results from computer simulations using those data, the various approaches used in the simulations and examines possible options for improving water application efficiency.

Methodology

Field measurements

To quantify current irrigation practices and have data available to validate the computer simulation results several irrigation parameters such as inflow, outflow, soil moisture deficit at irrigation, deep drainage and advance rate needed to be measured.

Inflow and Outflow

A measure of the total water applied to the top of the bay (inflow) and amount lost by runoff at the bottom of the bay (outflow) were determined. Both flows were gauged in several furrows at the top and bottom of the bay in a similar way by means of paddle wheel flowmeters connected to a datalogger. The paddle wheel produce an electrical signal with every revolution which is recorded and stored in the memory of the logger and downloaded to a PC at regular intervals for further processing. The flowmeters were housed in rigid PVC pipes and installed in furrows prior to each irrigation see Figure 11.1. Each flowmeter and pipe combination required an individual calibration which was obtained using a commercial water meter from the WA Water Corporation, a bucket and a stop watch.

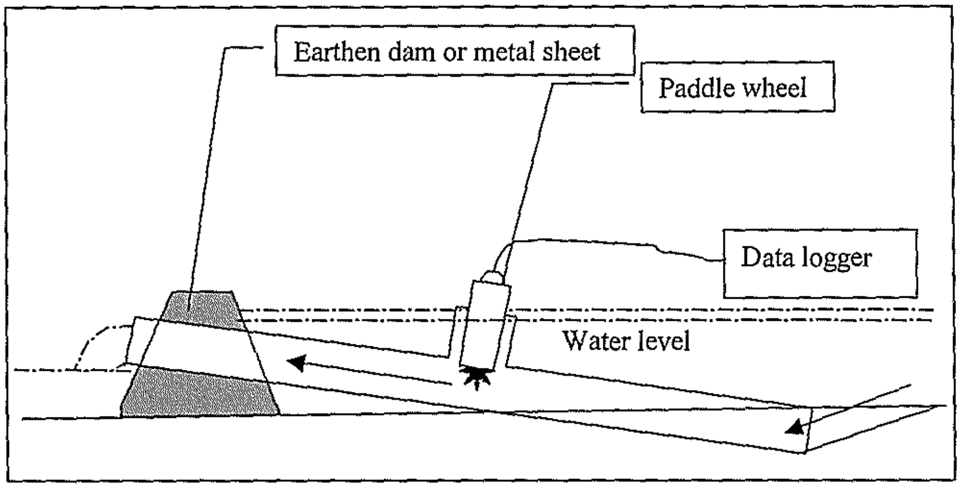


Figure 11.1. Flow meter installed in PVC pipe and placed in the furrow

Soil Moisture

Changes in soil moisture content, i.e. Soil Moisture Deficit (SMD) were obtained from measurements using a neutron moisture meter probe (NP) before and after each irrigation event or on some occasions a capacitance probe or EnviroSCAN® (ES). The measurements were taken at depths of 20, 30, 40, 50 and 60 cm and then at 80, 100 and 120 cm. Prior to the NP measurements a standard count was obtained in a drum filled with water following the procedure according to Greacen, *et al.* (1965). The counts of the NP were divided by the standard count and the ratio related to a moisture content using a calibration curve obtained from extensive soil sampling. The position of the neutron moisture meter access tube had a significant effect on the deficit measured. On some occasions with the access tubes positioned in the middle of the beds, only a small increase in the moisture content following an irrigation was measured. This was particularly the case with deeper furrows. After several trials it was found that positioning the tube in the shoulder of the bed gave a more reliable estimate of the average SMD in the root zone.

The measurements with the NP usually occurred about 1-2 days before and 1-2 days after irrigation for practical reasons. During those periods and during the irrigation evapotranspiration by the crop continues. This amount can be substantial under hot, dry and windy conditions (and had to be estimated) but was not included in the calculation of the SMD.

Deep drainage

Initially the deep drainage component was estimated by difference from Equation (1)

$$D = I - R - (DSM + Et) \quad (1)$$

where I the irrigation applied in mm, R the runoff in mm, DSM the change in soil moisture before and after irrigation in mm and Et the evapotranspiration occurring over the period between the NP measurements. It was found that in the low permeability soils (i.e. D expected to be small) of the ORIA this method was inaccurate. It was difficult to obtain a representative and accurate DSM as well as a reliable Et value. In addition an accurate I from the inflow and an R from the outflow measurements were also difficult to obtain with variations in magnitude (> 5 mm) between the individual furrows being similar to the expected deep drainage.

Another way to measure the deep drainage employed in irrigation research and in this project is to compare the inflow with the outflow when both have reached the steady state (i.e. no change in the flow is detected). This state, particularly in the outflow is often not achieved in the low permeability soils of the ORIA because the duration of common irrigations does not allow for that. Twice irrigations were extended to 48 hours. On one occasion the profile was fully wetted up and the outflow became similar to the inflow (i.e. indicating no deep drainage). On the other occasion the outflow remained smaller than the inflow even though the profile was not fully wetted up. Under such conditions the difference between the inflow and the outflow is then not solely deep drainage but includes also a component of continuous wetting-up of the beds. This was found to be the case particularly with deeper furrows.

Advance rate, water depth and furrow shape

Irrigation water advance rates during irrigation, which were used to calculate infiltration parameters, were obtained with resistor type sensors connected to a datalogger positioned at regular intervals down the furrow. The moment the water reached the resistor, the connection was shorted out across the resistor and the datalogger recorded a substantial drop in voltage which was clearly identifiable and could be used as a time stamp.

The depth of water in the furrow was obtained in a similar way but rather than using one resistor, several (up to 20) resistors were positioned in series along an insulated rod. With an increase in water level, the total resistance of the series of resistors dropped as the resistors were shorted out one by one. The change in resistance was converted to a change in water depth, using a calibration equation. This was replaced by manual measurements during the irrigation at times when the equipment was not available.

The furrow shape was determined manually prior to the irrigation and measured across the furrow at various positions. From the water depth and the furrow shape, the hydraulic radius (HR) defined as the ratio of the wetted area and perimeter in the furrow can be calculated. The HR is a major determining factor in the velocity of the water in the furrows.

Modelling using SIRMOD

SIRMOD model

Modelling of surface irrigation has been carried out to assess opportunities for improving irrigation efficiency. The model, SIRMOD (Surface Irrigation Model) developed at the University of Utah (Walker, 1993) was used in this study. It describes the flow through the furrow whilst allowing for continuous losses due to infiltration. The infiltration or infiltration properties of the soil are described using the Kostiakov-Lewis (K-L) empirical equation: $\mathbf{I = k\ t^a + t\ f_0}$ where I is the cumulative depth of infiltration, k and a are fitted parameters, t = the time and f_0 represents the infiltration at very long elapsed times. Both parameters, k and a were determined from actual irrigation events using an optimisation program developed at the University of Southern Queensland, Toowoomba (McClymont, 1995). For this calculation the inflow, advance rate of the water down the furrow (distance + time) and the wetted area were required. The f_0 was determined from the difference in inflow and outflow when both had come to a steady state.

Model testing

In the initial stages of the project the objective of the simulations were to test the ability of the model to simulate actual irrigation events using infiltration properties of the bay derived from measurements during the irrigations. At a later stage several bays were monitored to test the model for its ability to simulated irrigation events when bay length and duration were altered using infiltration properties obtained from previous irrigations.

The bays length and the duration were varied because those two parameters would not affect the infiltration properties of the soil. The infiltration properties are described empirically by the K-L equation and depend therefore on many factors that might affect the irrigation performance such as surface roughness, furrow shape, inflow, but also antecedent soil moisture. The bays length was altered by positioning outflow meters halfway the bay as well as at the end of the bay. Leaving certain furrows run longer altered the irrigation duration.

Model Extension

Instead of using infiltration properties for the different bays based on actual monitored irrigations it was investigated whether a general approach could be found to extend the use of SIRMOD to predict actual irrigations rather than simulating retrospectively. Three approaches were used: average parameters, Inflow-Outflow (IO) and the Instantaneous Crack-Fill (ICF) method and these will be described in the following sections.

Average Parameters

The use of individual infiltration separate parameters of each bay which depend on the growth stage of the crop, inflow, surface roughness, will produce very accurate simulations of the actual irrigations. This however requires elaborate and expensive measuring of irrigation parameters under many different scenarios. One approach to avoid the need for these measurements was to use the mean of the parameters obtained from a number of different irrigations in different bays across the ORIA. It was assessed whether one set of infiltration parameters (i.e. the mean) would be sufficient to describe the irrigations sufficiently accurately without any prior knowledge of the actual irrigations.

Inflow-Outflow

The approach of the Inflow-Outflow (IO) method is based on the concept that with some knowledge of the irrigations, i.e. inflow and the outflow, an estimate can be made of the total amount infiltrated, being the difference between the total inflow and outflow. With the information of the total infiltrated amount after for example 24 hours, an appropriate infiltration curve can be selected to simulate particular irrigations. The range of infiltration curves is illustrated in Figure 11.2.

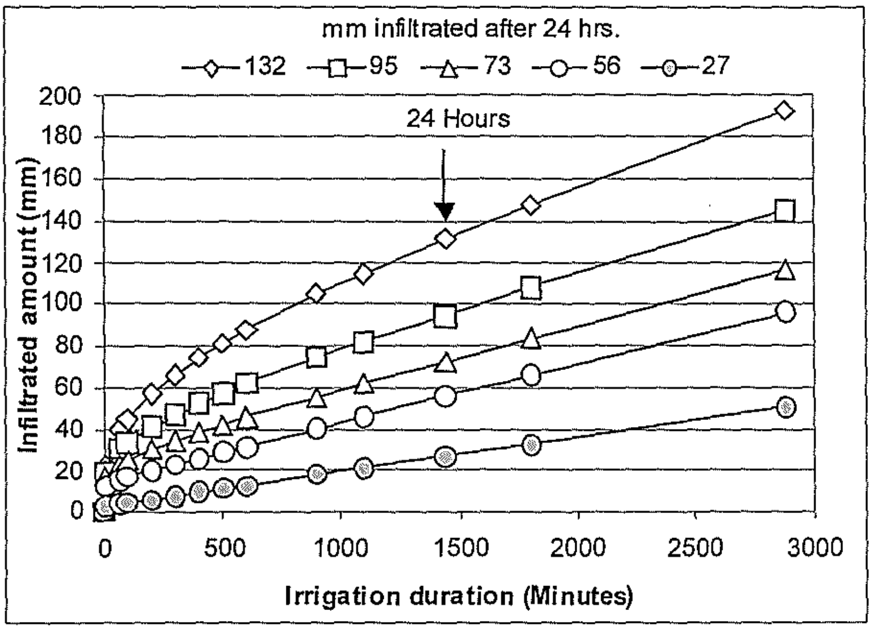


Figure 11.2. Range of infiltration curves used in the Inflow-Outflow method

<u>Instantaneous-Crack Fill</u>

From ES observations in block B27 it was obvious that infiltration into the clay soil happened initially very fast, as can be seen in Figure 11.3.

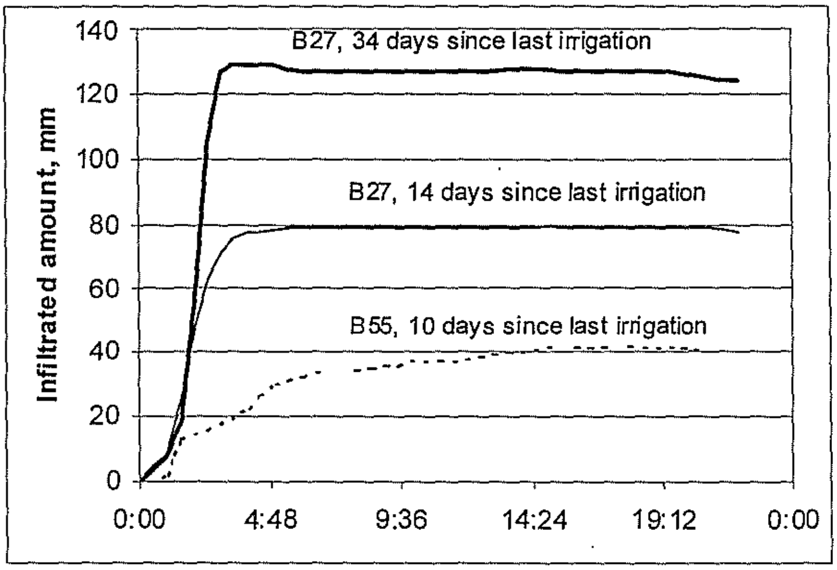


Figure 11.3. Infiltration behaviour of B27 at 34 and 14 days since last irrigation and B55 at 10 days since last irrigation.

From Figure 11.3 it can be seen that in less than 4 hours the profile of B27 is full. This is very common for the swelling and shrinking clay soils and has been described by various researchers such as Mitchell and Van Genuchten (1993) and Austin and Pendergast (1997) but not well documented in terms of real time infiltration measurements.

This behaviour can be described as Instantaneuos Crack Fill (ICF) bearing in mind that it still took about 4 hours for the profile to fully wet up. The volume of the crack is solely driven by the soil moisture deficit prior to irrigation, as illustrated in the figure by the difference in B27 between the 14 and 34 days since last irrigation. From the ES observation it was also concluded that deep drainage during the irrigations was very small and probably could be ignored. The description of the infiltration became therefore a matter of applying water to the surface that rapidly i.e. in 4 hours filled the cracks with the deep drainage component during irrigation being ignored. The newer version of SIRMOD (V6-4-98) allowed for the infiltration description by including a crack fill component with the K-L equation which then becomes $\mathbf{I} = \mathbf{CF} + \mathbf{k}\ \mathbf{t}^{a} + \mathbf{t}\ \mathbf{f}_0$ with **CF** as crack fill and the rest as in Equation 1. In this approach **k** and $\mathbf{f}_0$ were equal to zero and **CF** solely a function of the soil moisture deficit at irrigation. There was no need therefore to obtain advance rate data to derive the infiltration parameters.

This approach was satisfactory for several bays but not for all of them. Those bays did display a continuous infiltration during the irrigation and was far from instantanous. This behaviour is illustrated in Figure 4 by the infiltration at B55, where it took at least 14 hours to reach a maximum moisture content. This had to be reflected in the infiltration properties and SIRMOD was used employing the full K-L equation including a CF component with **k**, **a** and $\mathbf{f}_0$ NOT equal to zero (non-ICF), which in essence is fairly similar to the Inflow-Outflow method.

Results and Discussion

Field observations

A total of 45 irrigations were observed. All bays were planted to sugar cane at the time but the cane was at different stages of development. The measurements were generally taken during the dry season (April – end of November) since the irrigations are fairly regular during that period. These included commercial (30) as well as experimental irrigations (15). On a number of the irrigations the position of the NP tube had been such that unreliable soil moisture deficits were obtained so that the AE could not be calculated. The median irrigation duration of the commercial irrigations was 24 hours, applied water was 124 mm, outflow 41 mm, irrigation AE 61%, duration of the outflow 15 hours and the time to the tail drain 10 hours. The results of all the irrigations are presented in Table 11.1.

Wood *et al.* (1998) published a paper on benchmarking irrigation practices in the ORIA. Irrigation data such as frequency, number and duration of irrigations, time to reach the tail drain, duration of tail drain flow, water applied per irrigation and total water applied were obtained from a survey of sugar cane farmers. The median irrigation duration presented here is similar to that published. However the duration of the outflow is 8 hours longer than the survey found whilst the time observed for the water to reach the tail drain is 5 hours shorter. There is obviously a discrepancy between the measured times and the times assumed by the growers.

Tail drain flow duration, even though it is significant in the overall irrigation AE, is not a parameter that irrigators use as an important criterion, but perhaps it should be. In the ORIA irrigation duration is often determined by fixed time intervals such as 12, 18 or 24 hours rather than a maximum duration of tail drain flow. The duration of outflow in this case is thus the result of a given irrigation duration. Surprising and difficult to explain however is the discrepancy between our observed median water applied per irrigation of 124 mm and the range found in the survey of 320-380 mm applied. A possible but unlikely explanation is that substantial losses occur between the Dethridge Wheel (water record of the farmer) and the furrows (water record of the research project). If this were the case further work is required to reduce these losses.

Table 11.1. Summary of the data collected from commercial block irrigations.
C = a commercial irrigation and NC a non-commercial irrigation

Block	Date	Type	Irrigation Duration (hrs)	Deficit (mm)	Inflow (mm)	Outflow (mm)	Percent Outflow from Inflow (%)	Application Efficiency (%)	Outflow (hrs)	Time to Tail Drain (Hrs)
B19	12/05/98	C	18		108	40	37		14	10
B27	17/08/99	C	18	82	134	24	18	61	6	10
B27	31/08/99	C	12	48	84	26	31	57	7	6
B27	14/09/99	C	18	58	76	4	5	76	2	10
B27	28/09/99	C	24	65	145	70	48	45	10	10
B27	28/09/99	C	24	125	171	41	24	73	16	6
B27	12/10/99	C	18	71	107	39	36	66	10	8
B27	18/09/00	NC	48	66	301	225	75	22		
B27	12/10/00	C	18	71	108	33	31	66	10	8
B2b	25/08/98	NC	11	67	136	47	35	49	5	4
B2b	11/10/98	NC	6	5	68	33	49	7	4	2
B2b	11/10/98	NC	6	8	56	28	50	14	4	2
B2b	11/10/98	NC	6	8	56	16	29	14	4	2
B2b	7/12/99	NC	8	15	94	43	46	16	8	4
B2b	8/12/99	NC	10	33	131	64	49	25	7	3
B3b	24/09/97	NC	15		170	46	27		8	8
B44	14/10/98	NC	18	54	89	45	51	61	14	5
B44	14/10/98	C	25	65	122	60	49	53	24	5
B51	1/09/98	NC	16.5	Dry	75	36	48		12	7
B51	1/09/98	C	24	Dry	121	60	50		20	7
B54	14/09/98	NC	23	Dry	139	46	33		13	13
B54	14/09/98	C	20	Dry	127	22	17		15	8
B55	20/03/97	C	36		176		0		18	20
B55	2/04/97	C	42		202	50	25		30	17
B55	11/04/97	C	25		127	27	21		15	14
B55	19/04/97	C	25		132	34	26		28	12
B55	28/04/97	C	31		198	64	32		24	10
B55	7/05/97	C	29		170	45	26		20	11
B55	21/05/97	C	25		158	43	27		24	12
B55	31/05/97	C	27		160	48	30			
B55	9/06/97	C	23		121	42	35			
B55	20/06/97	C	22		114	30	26			
B55	5/07/97	C	25		101	43	43			
B55	23/07/97	C	22		103	24	23			
B55	24/04/98	C	18.5		98	56	57			
B55	4/05/98	C	24		123	37	30			
B68	12/08/98	C	30	101	125	32	26	81	13	21
B68	12/08/98	C	24	65	108	12	11	60	7	21
B69	20/04/99	NC	10	51	93	53	57	55	9	7
B69	20/04/99	C	15	56	145	76	52	39	14	7
B69	19/05/99	NC	8	38	78	29	37	49	7	7
B69	19/05/99	C	12	40	111	48	43	36	8	7
B76	24/10/00	NC	48	33	339	199	59	10		
B86	20/08/98	NC	12	Dry	71	41	58		10	4
B86	20/08/98	C	24	Dry	151	107	71		22	4
Median*			24		124	41	30	61	15	10
Min*			12		76	4	5	36	2	4
Max*			42		202	107	71	81	30	21

* Determined from only the commercial blocks

SIRMOD simulations

In irrigation modelling the two output parameters, advance rate and the outflow, are normally used to compare simulated with the actual irrigations.

Using measured irrigation parameters

Nineteen irrigations have been simulated using measured infiltration parameters from individual irrigations. A sample of these results is presented in Table 11.2.

Table 11.2. A sample of simulation results using infiltration parameters derived from actual irrigation events.

Bay	Length (m)	Inflow (l/sec)	Irrigation duration (hrs)	Water applied (mm)	Adv. Meas. (min)	Adv. Sim. (min)	Runoff Meas. (mm)	Runoff Sim. (mm)
B51	490	1.11	16.5	66	176	165	53	48
B68	1200	2.00	24.0	108	1338	1389	12	9
B2	180	1.12	11.0	135	296	330	46	46
B55_1	550	1.37	22.75	120	678	671	42	39
B55_2	550	1.40	22.3	115	747	700	30	28

Adv. = Advance time to end of bay; Meas. and Sim.: Measured and Simulated respectively.

The inflow sometimes varied during the course of the irrigation, whilst variability between furrows was sometimes considerable but overall there is a good agreement in Table 11.3 between measured and simulated advance rate and the runoff.

The results of all nineteen simulations are depicted in Figure 11.4. Whilst good agreement between the measured and the simulated advance rate was achieved, the simulated runoff was generally slightly underestimated compared with the measured.

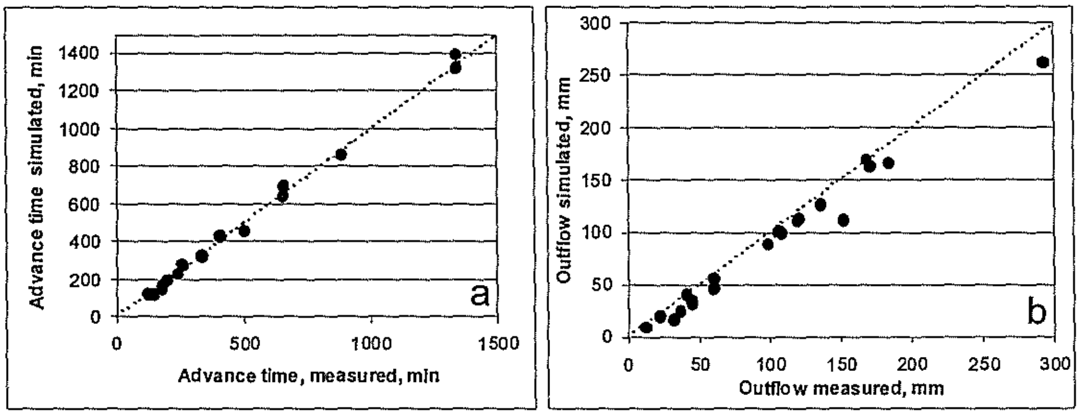


Figure 11.4. Measured vs.simulated advance rates (a), Measured vs.simulated outflow (b).

Simulations with variable bay length and duration

Several irrigations were arranged to examine the response to different irrigation durations and lengths of furrows. The same infiltration parameters, **a**, **k** and $\mathbf{f_0}$ as used for Table 11.1 were used in the simulation model to predict advance rate and runoff. The results of these simulations are presented in Table 11.3 and depicted in Figure 11.5.

Table 11.3. Simulation results for Bays 51 and B68.

Block	Length (m)	Inflow (l/sec)	Duration (hrs)	Applied (mm)	Adv. Meas. (min)	Adv. Sim. (min)	Runoff Meas. (mm)	Runoff Sim. (mm)
B51	240	1.11	16.5	153	176	165	108	99
	490	1.11	16.5	75	402	435	36	26
	240	1.23	24	245	176	152	169	155
	490	1.23	24	120	402	427	60	47
B68	550	2.00	24	197	652	639	99	88
	1000	2.00	24	108	1389	1338	12	9
	550	1.85	30	227	652	695	151	111
	1000	1.85	30	125	1389	1524	32	17

Adv. = Advance time to end of bay; Meas. and Sim.: Measured and simulated respectively.

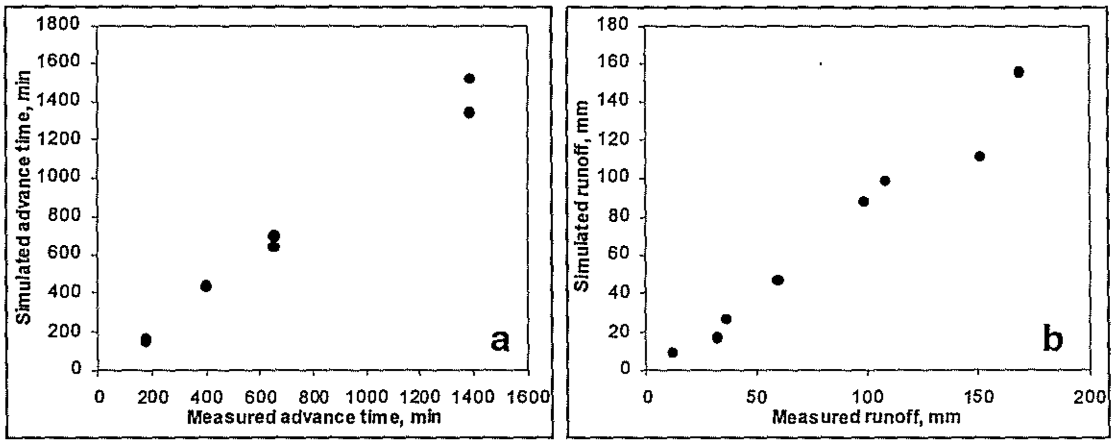


Figure 11.5. Comparison between the measured and the simulated advance time (a) and the runoff (b) using SIRMOD for various bay lengths and durations.

The simulated advance times and runoff agreed well with the measured variables except for B68 at 550 m and 30 hours when the runoff measured was 40 mm less then simulated runoff. So for a given condition SIRMOD is able to simulate various options (i.e. different irrigation durations and lengths of furrow) with a good degree of accuracy.

Simulations with mean infiltration parameters

The various infiltration parameters (**k**, **a** and $\mathbf{f_0}$) used in the simulations above were derived from irrigations on individual bays with some variation in infiltration parameters. In Table 11.4 the infiltration parameters used in the simulations are presented along with the mean of those parameters.

Table 11.4. Infiltration parameters and mean values used in the simulations.

Bay	a	k, mm/min^a	f_0
2b	0.200	0.0268	0.00011
44	0.245	0.0097	0.00005
51	0.257	0.0102	0.00005
54	0.213	0.0155	0.00006
55	0.087	0.0340	0.00006
68	0.200	0.0340	0.00002
86	0.200	0.0085	0.00003
Mean	0.2002	0.0198	0.000054

The simulations were run using these parameters and the relationships between simulated and observed advance time and runoff are presented in Figure 11.6. The mean and the standard deviation of the error between the observed and the simulated advance time was 12.6% and 42% respectively, while for the runoff, the mean error was 42% with a standard deviation of 65%.

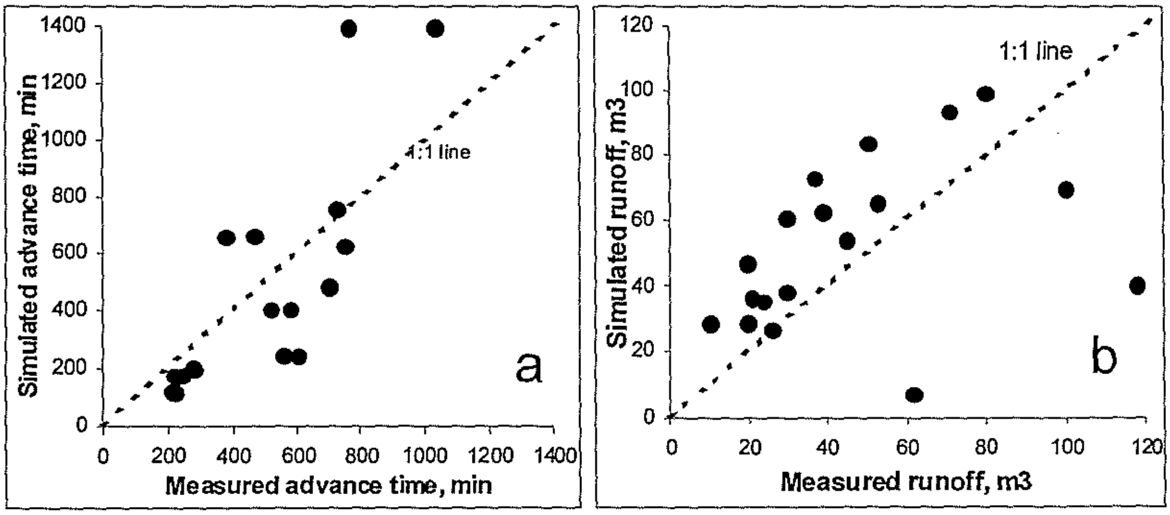


Figure 11.6. Simulated advance time as a function of the measured time (a) and simulated runoff as a function of the measured runoff (b).

A poor correlation between the measured and the simulated advance time and runoff was obtained using the generalised infiltration parameters. From the poor correlation it is concluded that more information regarding the infiltration of different bays and irrigations is required for accurate predictions of the irrigations. Using one set of parameters for all the bays and irrigations is clearly not sufficient.

Simulation Using the Inflow-Outflow Method

The results of the simulations in comparison with the actual measured advance time and the outflow using the IO method is portrayed in Figure 11.7.

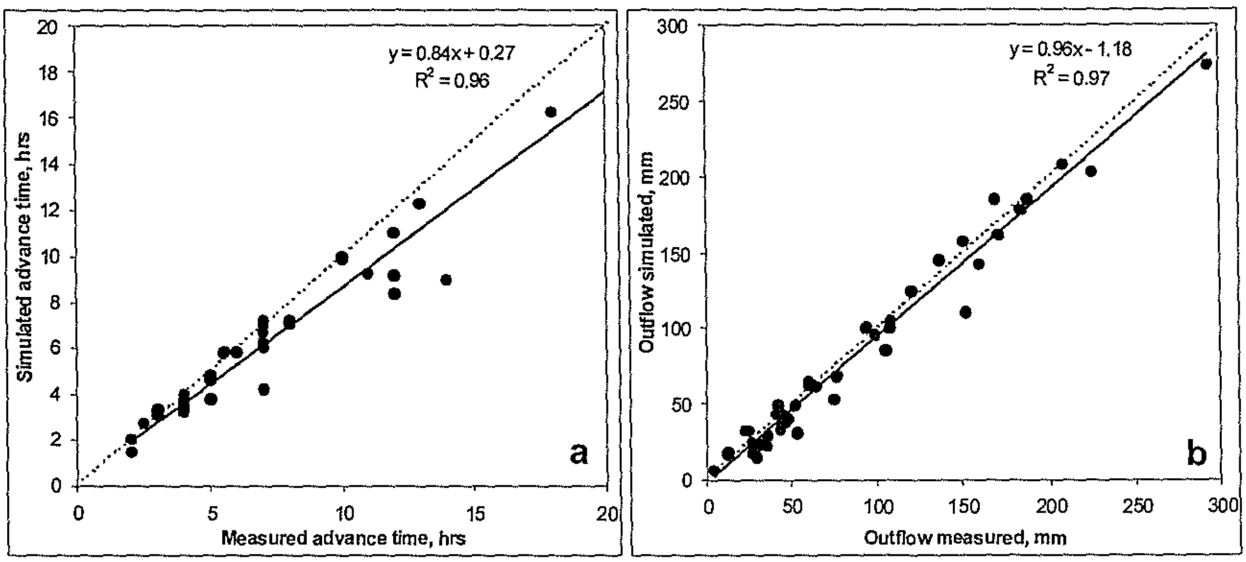


Figure 11.7. The simulated advance time compared to the measured time (a) and the simulated outflow compared to the measured outflow (b)

Using the measured inflow and the outflow and assuming an infiltration pattern, a good correlation was found between the simulated advance rate and the outflow and the actual measured time and outflow. The simulated advance rate tends to be underestimated for the longer durations without affecting the total outflow much. It is clear that with a little more information on the irrigations some good predictions of the irrigations can be made.

Infiltration Behaviour and Crack-Fill

The infiltration behaviour is described by the total amount of moisture stored in the soil as a function of time. Figures 11.8 and 11.10 illustrate that behaviour for various conditions encountered in several bays in the ORIA. As part of the study in several bays NP access tubes were installed at various positions down the furrow. Due to the position of the tube relative to the head ditch the inundation time at each position varied and could be determined. The change in soil moisture content at every position following irrigation was measured with the NP and plotted against the infiltrated amount at that point.

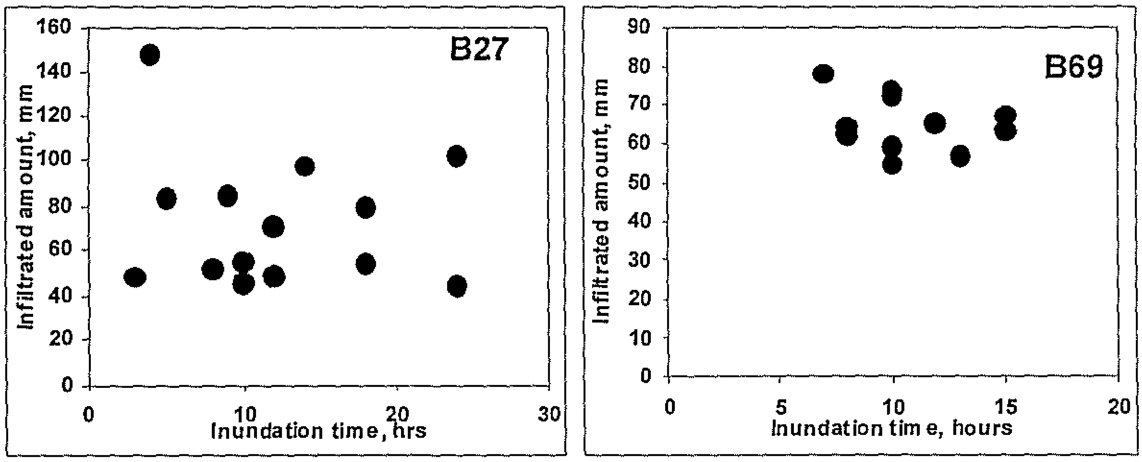


Figure 11.8. The infiltrated amount at irrigation as a function of the duration of inundation for a number of irrigations at Bay 27 and Bay 69.

As can be seen from Figure 11.8 no clear correlation was present between the inundation period and the amount infiltrated. The variation of the water applied was driven by the soil moisture stored in the profile prior to irrigation rather than the inundation time. The soil moisture stored in the profile determined the crack volume, as can be seen in Figure 11.9.

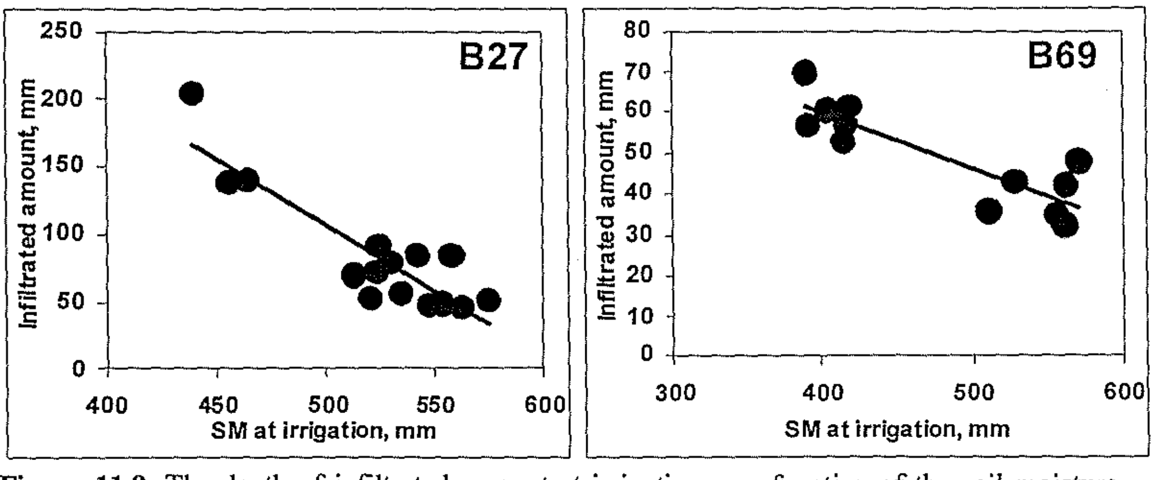


Figure 11.9. The depth of infiltrated amount at irrigation as a function of the soil moisture (SM) just before irrigation at Bay 27 and Bay 69.

As can be seen in Figure 11.10 some bays displayed a different infiltration behaviour. Rather than the total infiltrated amount being driven by the SM at irrigation it appeared to be driven by the duration of inundation.

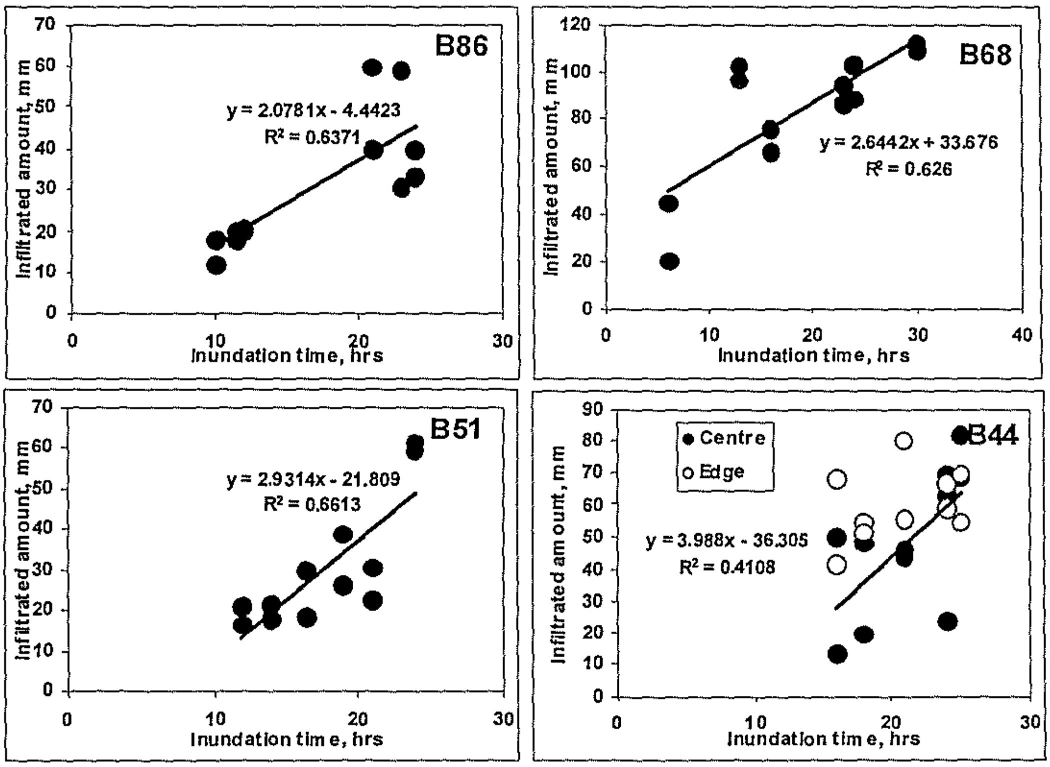


Figure 11.10. Infiltrated amount as a function of the inundation period of four bays (B86, B68, B51 and B44).

The duration of inundation had a great effect on the infiltrated amount. In all of these bays the tubes had been placed in the centre of the bed hence the NP readings only reflected the moisture changes in the centre of the bed. These changes often did not correspond with the total amount infiltrated as calculated from the difference in the inflow and the outflow of the bay. It was therefore concluded that the soil closer to the furrow had to be wetter than the beds to compensate for the dryness of the beds. The difference in the stored amount of water in the edge and the centre of the bed, as shown in Figure 11.10 for B44, confirms that trend.

A major difference between B27 and B69 and B86, B68, B51 and B44 is the shape of the furrow. The furrow profile of B27 and B69 was more shallow and had a distinct flat-base profile whilst the other four blocks had deeper and more distinct 'V'-shaped profiles. Figure 11.11 illustrates the various profiles.

The effect of furrow profile on irrigation performance is also illustrated by the following. Bay 27 changed from a shallow profile in 1999 to a deeper furrow in 2000, see Figure 11.11 (B27, 18/09/00). This was done because the grower was not happy with the furrow profile and how the bay drained during the wet season. This change in furrow shape/depth affected the behaviour of the subsequent irrigation. From a slow moving rapidly infiltrating furrow it changed to a fast moving slowly infiltrating furrow. The irrigation in September 2000 (18/09/00) with a similar inflow rate and at a similar soil water deficit as an irrigation in September 1999 took 5 hours less to advance to the end of the bay due to the change in furrow profile/depth. The change in furrow profile had a large effect on the performance of the irrigation. The deeper 'V'-shaped furrows took longer to wet up, they reached the tail drain faster, the runoff losses were higher and therefore resulted in a lower AE.

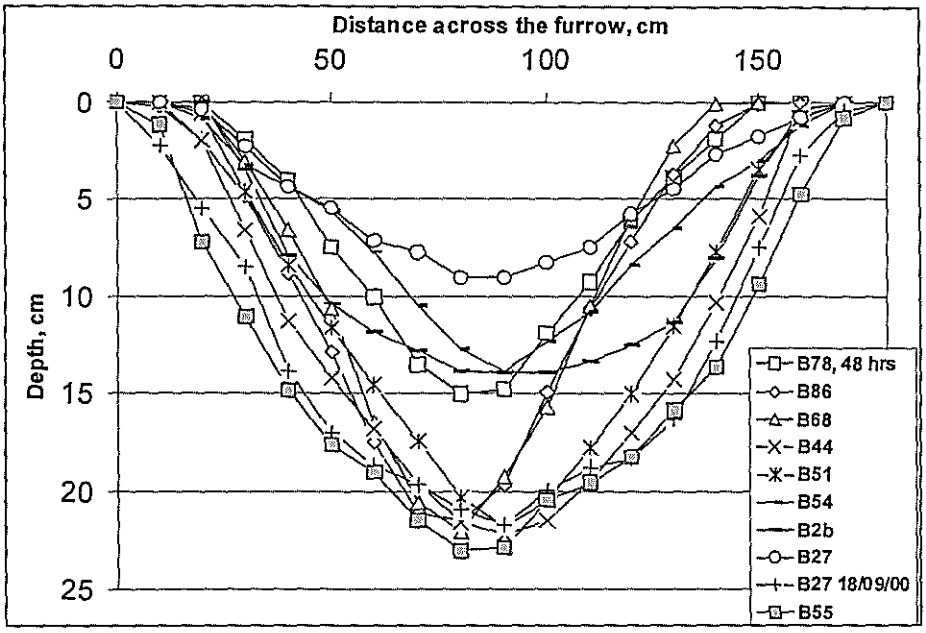


Figure 11.11. Furrow profiles of the bays as indicated in the legend. The profiles were taken just prior to the irrigations.

The reason for this difference appears to be in the hydraulic radius (HR) of the furrow. The HR is defined as the ratio of the wetted area (A) and the wetted perimeter (P) during the irrigation. There is thus a theoretical relationship between HR and the water velocity in a channel, according to the Chezy formula which is defined as:

$$V = C\,(\mathbf{HR} \times s)^{\wedge 1/2} \qquad (2)$$

where **V** is the velocity in meters per second, **C** is a coefficient dependent on the roughness of the channel (Manning's *n*), **HR** and the slope s. So with an increase in **HR**, an increase in the velocity is expected. In Table 11.5 several furrow properties as well as other dimensions of the flow are presented such as A, P, HR and water depth.

Table 11.5. Furrow and hydraulic flow dimensions, furrow inflow, furrow length, time to reach the tail drain and the advance rate in the furrow for various bays.

Bay	Furrow depth (cm)	A (cm^2)	Water depth (cm)	P (cm)	HR (cm)	Inflow (l/sec)	Furrow length (m)	Time to tail drain (min.)	Advance rate (m/min)
44	22.1	213	5.5	61.1	3.49	1.44	580	500	1.16
51	21.7	167	5.8	51.3	3.26	1.11	450	402	1.12
27	9	124	3.1	60.3	2.06	0.95	300	840	0.36
54	13.9	339	7.8	81.6	4.16	1.05	350	555	0.63
86	21.3	516	12	74.5	6.93	1.2	430	240	1.79
68	22	251	8.5	53.5	4.71	1.8	1000	1338	0.75
69	14.1	268	5.5	81.1	3.31	1.2	260	446	0.58
2B	13.9	228	3.9	91	2.52	1.07	170	296	0.57
27, deep	21.6	299	6	91	3.28	0.8	300	480	0.63
76	15	414	9.2	83	5	1.2	400	529	0.76
69	14.1	234	9.1	71	3.3	1.2	260	453	0.57

Graphically displaying the data from Table 11.5, as is done in Figure 11.12, generated some useful relationships.

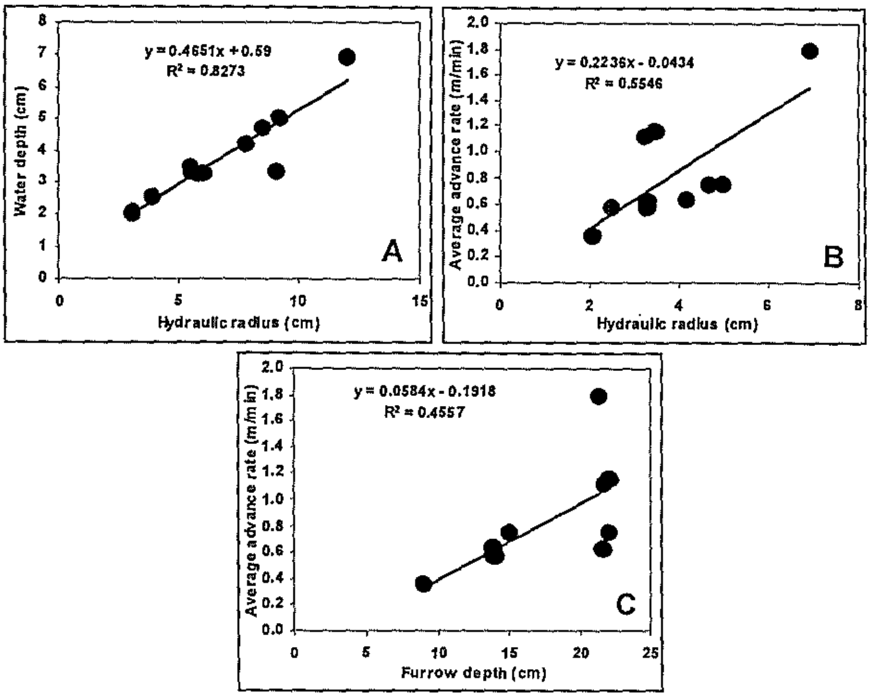


Figure 11.12. The water depth in the furrow as a function of the hydraulic radius (A), the average advance rate in the furrow as a function of the hydraulic radius (B) and the average advance rate as a function of the furrow depth (C).

There is clear relationship between the measured water depth in the furrow and HR. There is also some relationship ($R^2 = 0.55$) between HR and the advance rate in the furrow even though the relationship is not as good because the flow in the furrow is not solely dependent on HR but also on C and the slope. A similar relationship exists between the depth of the furrow and advance rate. These relationships provide an explanation for the measured dependency of the advance rate on the shape/depth of the furrow. With a change in furrow shape the water depth in the furrow is increased, which in turn increased the velocity of the water in the furrow. It is difficult to separate the shape from the depth of the furrow because they are confounded in the commercial irrigation furrows and thus have been used in conjunction.

From an irrigation application efficiency point of view is would be more advantageous to have shallower and broader furrows in which the water flows more slowly with more opportunity for crack fill and less tail water runoff. From a drainage point of view in the wet season the deeper furrows might be preferred even though with properly laser levelled bays and clean tail drains this issue might be of lesser importance.

In the sandy loam soils of the Burdekin Delta (Qld) where the effect of furrow shape was investigated by the BSES (Holden *et al*, 1998), it was found that the deeper 'V'-shaped furrows had a better AE than the 'U'-shaped furrows. Where lateral infiltration into the beds is not a problem, the deeper 'V'-shaped furrows limited the overall opportunity time for infiltration because water in these furrows reached the tail drain faster than the 'U'-shaped furrows. In the Burdekin Delta deep drainage losses are significant and by changing furrow shape from a 'U'-shape to a 'V'-shape these can be substantially reduced. This issue does not apply to the ORIA, at least not in the bays we have investigated, because the deep drainage component tended to be much smaller.

Modelling Crack Fill

As was shown before, SIRMOD can be used to simulate various irrigations accurately both in terms of predicted advance times and runoff, two parameters often used in the assessment of irrigation simulations. The third parameter is the amount infiltrated and stored in the root zone during the irrigation. On all occasions soil moisture changes detected with the NP should reflect the calculated moisture stored in the root zone. The application of generalised infiltration parameters did not provide good estimates of the advance rate and the runoff. The modelling approach was then changed and an allowance made for infiltration behaviour typical for clay soils whilst distinguishing between 'U'-shaped and 'V'-shaped furrows.

The approach with the use of SIRMOD has been two fold. Firstly the instantaneous crack fill (ICF) has been used for those bays that have 'U'-shaped furrows and secondly the non-ICF method was employed for bays with 'V'-shaped furrows. Simulations using the ICF for the 'U'-shaped furrows gave the following results, presented in Table 11.6.

Table 11.6. Simulated and measured outflow, advance time and infiltrated amounts (Infiltr) using the ICF method with negligible deep drainage.

Bay	Date	Outflow Sim (m^3)	Outflow Meas (m^3)	Advance Sim (min)	Advance Meas (min)	Infiltr. Sim (mm)	Infiltr. Meas (mm)
27	16/08	12	12	974	960	111	111
	12/10	22	21	757	640	71	80
	31/08	18	13	465	420	47	55
	28/09	35	35	790	630	75	80
	28/09	22	21	1121	960	128	128
2B	25/08	14	14	480	300	96	96
	7/12	17	12	219	164	35	40
	8/12	20.5	18	302	229	58	58
54	14/09	29	29	954	991	94	94

Sim = Simulated, Meas. = Measured

Good agreement was achieved in B27 and B54 between all three measured and simulated parameters **ONLY** using the crack fill component, based on the soil moisture deficit as a variable. In 2b the agreement was good in the outflow but not in the advance rate. It appears that this bay might be subject to some deep drainage.

When SIRMOD is applied to bays with the 'V'-shaped furrows, such as B44, it was found that the ICF approach is no longer applicable. A more complex infiltration description is then necessary including a component, the base intake, f_0, which resembles the sorption into the beds as a long term infiltration component as well as the transmission component of moisture passing below the root zone as deep drainage.

Little is known about the infiltration behaviour of the bays with distinct 'V'-shaped profiles when irrigated at larger deficits but it is reasoned that the crack fill component will become more pronounced, as illustrated in Figure 11.13 using a different deficit (MC) at irrigation. The constant infiltration rate later during the irrigation which resembled the sorption into the beds, is 60mm/24hr = 2.5 mm/hr which is close to the average slope (2.65 mm/hr) of the regression lines fitted through the observation points in Figure 11.10.

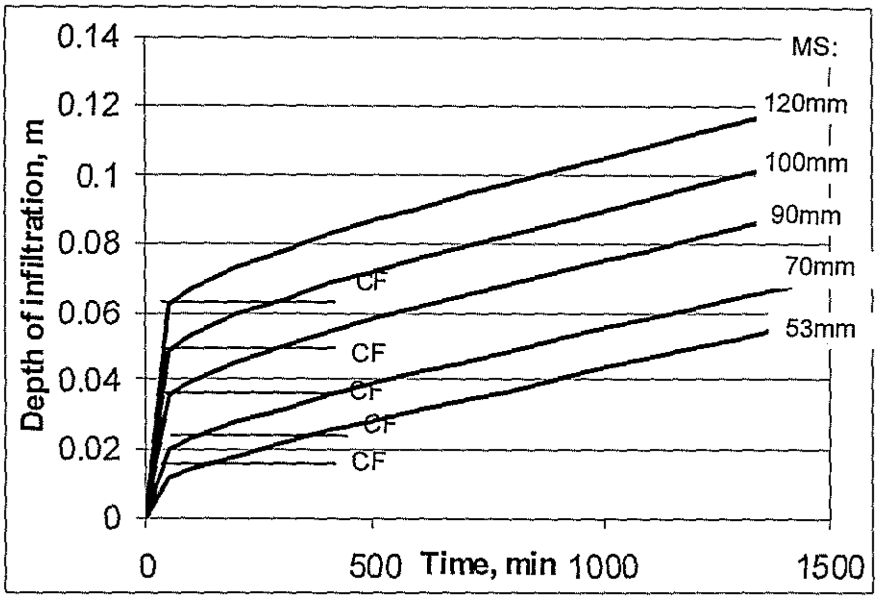


Figure 11.13. Infiltration patterns for B44, a block with a deep 'V'-shaped furrow profile for various levels of Moisture Stored (MS) during the irrigation. CF indicates the level of crack fill.

Using the infiltration curve for a MS of 53 mm, based on the deficit at irrigation needing to be replenished, the following results presented in Table 11.7 were achieved simulating an irrigation in B44.

Table 11.7. Simulation results using SIRMOD on B44 for different bay lengths and irrigation durations.

Bay length and duration	Water applied (mm)	Advance time (min) Meas.	Advance time (min) Sim	Outflow (mm) Meas	Outflow (mm) Sim
300m, 18hrs	174	195	187	120	118
300m, 25hrs	242	195	187	183	174
580m, 18 hrs	90	500	446	45	36
580m, 25 hrs	125	500	446	60	59
Infiltration (mm) at different position in the bay:		Meas. mm	Sim, mm		
Top, 18hrs		53	54		
Centre, 18 hrs		54	53		
Bottom, 18 hrs		filled	48		
Top, 25hrs		63	66		
Centre, 25 hrs		67	65		
Bottom, 25 hrs		filled	60		

Meas. = Measured, Sim. = Simulated. Filled = filled with water backed up the furrows and filled the NP tubes.

It can be seen that the simulated advance time, outflow and the infiltrated amount compared very well with the measured even though the simulated outflows at 580 m and 18 hrs were slightly under-predicted.

From these results it has been concluded that the current approach using the ICF and the non-ICF method, would be suitable to develop look-up tables. The non-ICF is in essence similar to the IO-method described earlier. Both describe the infiltration into the soil with a continuous infiltration component later in the irrigation. The non-ICF method still assumes a crack-fill component which is filled rapidly, followed by a continuous infiltration rate of about 2.5 mm/hr. The crack-fill component is determined by the deficit at irrigation. The IO-method requires knowledge of the total amount infiltrated and on that basis an infiltration curve is selected which looks very similar to the non-ICF infiltration curve.

Look-up Tables

There are several ways to improve the AE. The AE can be improved by changing the inflow rate, the bay length, the irrigation duration, the soil moisture deficit at irrigation, and so on. Look-up tables can be used to establish relationships between a number of variables that can be changed to improve the AE.

Instantaneous Crack Fill (ICF) approach applied to U-shaped furrows

Using the ICF approach the modelling of the irrigation becomes very straightforward because the infiltration properties are driven by the soil water deficit at irrigation which can be easily determined with in-field measurements or simulated with crop growth models. Irrigations were simulated for a different CF at irrigation and presented in Table 11.8. The soils at the various bays have been described in terms of Drained Upper Limit (DUL), Lower Limit (LL) and Field Capacity (FC), information often required by crop growth models.

Table 11.8. Lookup table for Blocks 27 and 2B for irrigations of a single duration and different CF.

	Duration	CF (mm)	AE (%)	Runoff (m^3)	Runoff /Appl
B 27	24	200	nr	nr	nr
DUL = 808 mm	24	180	100	0	0
LL = 540 mm	24	150	83	15	0.15
FC = 783 mm	24	111	62	34	0.37
	24	100	55	40	0.44
	24	50	27	65	0.72
	28	180	84	16	0.16
B 2B	10	150	nr	nr	nr
DUL = 771 mm	10	130	100	0	0
LL = 548 mm	10	100	76	8.9	0.23
FC = 709 mm	10	80	61	14.6	0.39
	10	60	46	20.4	0.54
	10	40	30	26.1	0.69

DUL =Drained Upper Limit; LL =Lower Limit; FC =Field Capacity achieved after normal irrigation, CF =Crack Fill at irrigation; AE = Application Efficiency; Ru = Runoff; Ru/Appl = Fraction Runoff to Water Applied, nr = not applicable because the water did not reach the end of the bay.

The use of ICF is a good approximation of reality but an approximation nonetheless. As can be seen from Figure 11.2 it takes generally a little longer (ie. up to 4 hours) before the profile is saturated. It is therefore not feasible to apply exactly the same amount of water as the volume of cracks. The water needs to run for an additional 4 hours before the profile is saturated. This is illustrated by the 28 hr irrigation in Table 11.8 during which runoff losses occur and a reduction in the AE from 100 % to 84 %.

A more extended look-up table with variable bay lengths, irrigation durations and inflow is included in this report as Table 11.9.

Table 11.9. Look-up table for a flat base shallow furrow, characterised by an instantaneous crack fill with varying inflow rates, lengths of bay and duration of irrigation. Values in the matrix are the **Application Efficiencies (AE)** Zero deep drainage is assumed for this table and an additional irrigation duration of 4 hours to allow for a slower than instantaneous crack fill such as observed with the Enviroscan in B27 is included in the duration.

	1 l/sec					1.5 l/sec					2 l/sec				
CF = 50mm	Length, m	10hrs	18 hrs	24 hrs	32 hrs	Length, m	10hrs	18 hrs	24 hrs	32 hrs	Length, m	10hrs	18 hrs	24 hrs	32 hrs
ESW = 193 mm	200	50	28	21	16	200	33	19	14	10	200	25	14	10	8
Refill = 97%	400	----	56	42	31	400	67	37	28	21	400	50	28	21	16
FC = 783 mm	600	----	----	63	47	600	----	56	42	31	600	----	42	31	23
DUL = 808 mm	800	----	----	----	63	800	----	74	56	42	800	----	56	42	31
LL = 540 mm	1000	----	----	----	78	1000	----	----	69	52	1000	----	69	52	39
			1 l/sec					1.5 l/sec					2 l/sec		
CF = 100mm	Length, m	10hrs	18 hrs	24 hrs	32 hrs	Length, m	10hrs	18 hrs	24 hrs	32 hrs	Length, m	10hrs	18 hrs	24 hrs	32 hrs
ESW = 143 mm	200	----	56	42	31	200	----	37	28	21	200	50	28	21	16
Refill = 97%	400	----	----	83	63	400	----	74	56	42	400	----	56	42	31
FC = 783 mm	600	----	----	----	----	600	----	----	83	63	600	----	----	63	47
DUL = 808 mm	800	----	----	----	----	800	----	----	----	83	800	----	----	83	63
LL = 540 mm	1000	----	----	----	----	1000	----	----	----	----	1000	----	----	----	78
			1 l/sec					1.5 l/sec					2 l/sec		
CF = 150 mm	Length, m	10hrs	18 hrs	24 hrs	32 hrs	Length, m	10hrs	18 hrs	24 hrs	32 hrs	Length, m	10hrs	18 hrs	24 hrs	32 hrs
ESW = 93 mm	200	----	83	63	47	200	----	56	42	31	200	----	42	31	23
Refill = 97%	400	----	----	----	----	400	----	----	83	63	400	----	----	63	47
FC = 783 mm	600	----	----	----	----	600	----	----	----	----	600	----	----	----	70
DUL = 808 mm	800	----	----	----	----	800	----	----	----	----	800	----	----	----	----
LL = 540 mm	1000	----	----	----	----	1000	----	----	----	----	1000	----	----	----	----

DUL =Drained Upper Limit; LL =Lower Limit; FC =Field Capacity achieved after normal irrigation, PESW =Plant Extractable Soil Water = DUL–LL; CF =Crack Fill at irrigation; ESW =Extractable Soil Water still in profile at irrigation = CF – LL; AE = Application Efficiency = Depth Stored in Profile/Depth Applied as irrigation; RF =Refill = (CF + ESW)/PESW.

It should be pointed out that at no stage is the DUL achieved during the irrigation. The DUL is only obtained after prolonged ponding with enough hydraulic head for a sufficiently long time to wet up the deeper soil layers. This is never achieved during the irrigations, not even during the wet season. It was found that only moisture profiles in the tail drains and the supply channels will approach the DUL. They are probably also the places where most of the deep drainage occurs.

<u>Non-Instantaneous Crack Fill Approach</u>
In a similar manner with different infiltration functions the following look-up Table 11.10 was established for B44, a bay that has distinct 'V'-shaped furrows.

Table 11.10. Look-up table for B44 which has a distinct 'V'-shaped furrow profile.

B 44	**Duration, hrs**	**MS, mm**	**AE, %**	**RF,%**
	18	50	50	90
DUL = 1111 mm	24	50	42	100
LL = 872 mm	24	70	55	94
FC = 985mm	32	70	43	100
	24	100	77	92
	32	100	68	100

DUL =Drained Upper Limit; LL =Lower Limit; FC =Field Capacity achieved after normal irrigation; MS = Moisture stored during irrigation; AE =Application Efficiency; RF = Refill percentage

As shown in the table the AE increases with MS for a given duration. More water is stored in the soil profile and less is lost as runoff. The 24 hrs at MS = 100mm results in AE of 77 % but the Refill (RF) is 92 %, indicating that the 100 mm is not applied across the bay evenly and the bottom section is under-irrigated. It should therefore be irrigated longer to achieve a RF of 100 % which results in a drop in the AE to 68 %.

An alternative approach to the V-shaped furrows is to use smaller siphons to reduce the inflow and therefore reducing the runoff losses. A smaller inflow will however reduce the water depth in the furrow which might increase the time it takes to wet-up the beds.

A more extended look-up table is provided as Table 11.11 for B44, a bay representing bays with deep V shaped furrows for variable bay lengths, irrigation durations and variable inflow rates.

Table 11.11. Look-up table for a deep V-shaped furrow, characterised by a slow infiltration process with varying inflow rates, lengths of bay and duration of irrigation. Values in the matrix are the **Application Efficiencies (AE)** Zero deep drainage is assumed for this table.

		1 l/sec				1.5 l/sec				2 l/sec			
dSM	50	**Length (m)**	**18 hrs**	**24 hrs**	**32 hrs**	**Length (m)**	**18 hrs**	**24 hrs**	**32 hrs**	**Length (m)**	**18 hrs**	**24 hrs**	**32 hrs**
ESW	63	200	----	21	15	200	----	14	10	200	13	10	8
FC	985	400	----	42	43	400	----	27	21	400	----	20	15
DUL	1111	600	----	62	47	600	----	42	31	600	----	31	23
LL	872	800	----	----	62	800	----	55	41	800	----	40	31
PESW	239	1000	----	----	77	1000	----	69	52	1000	----	52	39
		1 l/sec				1.5 l/sec				2 l/sec			
dSM	70	**Length (m)**	**18 hrs**	**24 hrs**	**32 hrs**	**Length (m)**	**18 hrs**	**24 hrs**	**32 hrs**	**Length (m)**	**18 hrs**	**24 hrs**	**32 hrs**
ESW	43	200	----	28	21	200	----	19	14	200	----	14	10
		400	----	----	43	400	----	37	29	400	----	29	21
		600	----	----	65	600	----	54	43	600	----	42	32
		800	----	----	----	800	----	----	58	800	----	----	43
		1000	----	----	----	1000	----	----	72	1000	----	----	55
		1 l/sec				1.5 l/sec				2 l/sec			
dSM	100	**Length (m)**	**18 hrs**	**24 hrs**	**32 hrs**	**Length (m)**	**18 hrs**	**24 hrs**	**32 hrs**	**Length (m)**	**18 hrs**	**24 hrs**	**32 hrs**
ESW	13	200	----	----	31	200	----	27	20	200	----	----	15
		400	----	----	60	400	----	54	41	400	----	----	31
		600	----	----	----	600	----	----	60	600	----	----	46
		800	----	----	----	800	----	----	----	800	----	----	60
		1000	----	----	----	1000	----	----	----	1000	----	----	----
		1 l/sec				1.5 l/sec				2 l/sec			
dSM	120	**Length (m)**	**18 hrs**	**24 hrs**	**32 hrs**	**Length (m)**	**18 hrs**	**24 hrs**	**32 hrs**	**Length (m)**	**18 hrs**	**24 hrs**	**32 hrs**
ESW	-7	200	----	----	37	200	----	32	25	200	----	24	19
		400	----	----	72	400	----	----	50	400	----	47	37
		600	----	----	----	600	----	----	72	600	----	----	56
		800	----	----	----	800	----	----	----	800	----	----	----
		1000	----	----	----	1000	----	----	----	1000	----	----	----

dSM = Change in soil moisture following irrigation. ----: indicates an in-complete filling of the profile

Conclusions

The irrigation application efficiencies of irrigated bays of sugar cane were determined through direct measurement, with data obtained used in simulation modelling to predict optimum duration of irrigation and bay length. Measured runoff losses observed ranged from 5 to 71% of water applied. The median of the measured commercial irrigations gave similar results as a grower survey in terms of irrigation duration and applied water but a longer duration of tail water flow and a shorter time for water to reach the tail drain.

Deep drainage in most bays under irrigation that have been investigated by us appeared to be minimal and has been neglected in the modelling of irrigations using the ICF approach. Except for some bays it is assumed that deep drainage predominantly occurs during or shortly after the wet season. A time when little irrigation is used.

The use of one set of average infiltration parameters did not simulate the irrigations accurately. Some more information in terms of infiltration behaviour using the Inflow-Outflow method is required to improve the simulation results.

With some information on the inflow and the outflow during the irrigations, good predictions can be made of the irrigation. In some bays in the ORIA the Instantaneous Crack-Fill method provides a good approximation of the infiltration behaviour. These bays have without exception 'U'-shaped furrow profiles. Other bays in the ORIA with deep 'V'-shaped furrow profiles were found to have a different infiltration pattern, characterised by long and slow infiltration.

The simulation of the irrigation can be done successfully using the ICF approach or a standard infiltration (non-ICF) with a base infiltration term depending on the shape of the furrow profiles but both as a function of the deficit at irrigation. The base infiltration term would reflect the sorptivity into the beds and some component of deep drainage.

The AE improves considerably with an increase in the deficit at irrigation both for bays with 'U'-shaped and with 'V'-shaped furrows. Given the lack of or the very small deep drainage component the best improvement in AE is achieved by minimising the runoff losses through the tail drain by extending the irrigation interval (i.e. increase the deficit at irrigation) by reducing the inflow and/or changing the furrow shape.

Accessions to the groundwater are facilitated by prolonged ponding in the tail drain and the supply channels given the saturated profiles and the large hydraulic head in these features. Reduction of tail water runoff and the rapid removal of water from the tail drains is therefore essential.

12. IRRIGATION GUIDELINES

At the beginning of the project the growers were largely 'experimenting' with different irrigation scheduling methods. One of the key outcomes of this project was to examine the water requirements of sugarcane and develop irrigation scheduling guidelines for Ord growers.

Many different methods of developing irrigation guidelines have been developed and introduced to industry over the years. Many of these various methods were examined for suitability for use in the Ord. A workshop to present the results of the irrigation work was held in early 2001. All data available was presented to those present. At this workshop a decision was taken, after much discussion and consideration, to develop a table of daily intervals as a guide to scheduling irrigation of sugarcane at a range of different harvest dates.

Development of irrigation scheduling guidelines

Recent research has provided the following four key pieces of information that have been used to develop the guidelines for use by farmers for scheduling furrow irrigation of sugarcane in the ORIA.

1) Plant available water holding capacity (PAWC), which is a characteristic of soil hydraulic properties and rooting depth, was measured in situ for three major soil type variations of Cununurra clay in the ORIA (Muchow *et al.*, 2001). These soils are typically used for sugarcane production.
2) It was noticed that irrigation did not fully wet up the soil because of surface sealing after swelling of the 2:1 lattice clays prevalent in these soils. The amount of water in the profile after irrigation ranged from 75 to 85% of PAWC.
3) Irrigation trials indicated that cane yield was not affected until the crop had extracted about 50% of PAWC. From this knowledge, farmers selected two target deficits, one at 50% of PAWC, the other at 40% for irrigation scheduling.
4) The amount of water used by the crop on a daily basis was estimated by the APSIM-Sugarcane model. This model has been found to represent the growth of sugarcane under a wide range of conditions (Keating *et al.*, 1999). However, under Ord conditions, radiation use efficiency and hence crop water use had to be reduced after the crop had reached a certain biomass threshold (30 t/ha or about 80 t/ha of cane) in order to match simulated and measured crop water use and yield. Estimates of daily crop water use were not allowed to exceed $1.25*ET_0$ based on BREB research in the Burdekin and in Swaziland (McGlinchey and Inman-Bamber, 2002).

Information on PAWC for varying soil types, percentage of profile filling with irrigation and target deficit was used to generate further information on water available for use by the crop between irrigations (Table 12.1). This was then used in the APSIM model in association with long term climatic data from the Frank Wise Institute to provide a daily interval on which to re-irrigate cane at different stages of growth (Table 12.2). The system has an accuracy of (+/- 2 days) which is more than adequate given that the sensitivity of the flood irrigation system is also about 2 days. This daily interval method was also selected with the knowledge that sugarcane, to a large extent is not responsive to irrigation practice, except under extreme irrigation schedules. Given that the sugarcane was unlikely to suffer long term damage with a system accurate to a within +/- 2 days and the irrigation system itself was also inherently inaccurate, it was difficult to justify increasing the accuracy of the scheduling system.

Table 12.1. The amount of water available for plant use for three ORIA Cununurra clay soil types with varying PAWC, assuming 80% refill with irrigation and with target deficit of 50% PAWC.

Soil Type	PAWC (mm)	Plant available water after irrigation with 80% refill (PAWC*80%)	Target soil water deficit (PAWC*50%)	Water available with 80% refill and 50% target deficit (PAWC*80%) - (PAWC*50%)
1	169	135 mm	85 mm	50 mm
2	190	152 mm	95 mm	57 mm
3	225	180 mm	113 mm	67 mm

When the results of the APSIM simulations were first presented to growers, best-bet intervals were provided for different rainfall scenarios. Growers however preferred to account for rainfall themselves and adjust irrigation intervals accordingly. Hence guidelines provided (Table 12.2) use simulations developed assuming no rainfall.

Guidelines developed indicate that crops harvested on 1 August should receive an initial irrigation soon after harvest, with the second irrigation occurring 40-60 days later. However, these early irrigations are often influenced by individual farmer management practices, such as fertiliser application and herbicide incorporation. Scheduling for October through to January would require irrigation to occur every ten days, then thirteen days for February and March, and so on until July when the crop would begin the dry down period (DD) prior to harvest, with irrigation intervals adjusted for rainfall as necessary, throughout.

These guidelines have provided an effective extension tool to quickly update irrigation recommendations based on current research work being conducted in the Ord. Growers have used the tables as a means to modify irrigation scheduling in conjunction with their own experience in cane irrigation. As familiarity with scheduling principles increases, it is feasible that some growers will move to a more precise scheduling method, such as the use of crop factors and the water balance technique. Closer attention to matching crop water demand and supply will also be driven to a large extent by the likely increase in the cost of water and by requirements for more efficient use of water and improved environmental management.

Table 12.2. Irrigation scheduling guidelines for sugarcane for three harvest dates and three soil water deficits based on long term climate data

(a) Conservative Schedule – to remove 50% of plant available water (FESW = 0.5)

		Month of year											
	Harvest date	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
	1 JUNE	10	11	11	12	DD			12	10	9	9	9
	1 AUGUST	9	10	12	12	15	19	DD			9	9	9
	1 OCTOBER	9	10	11	12	14	18	18	15	DD			9

(b) Optimal Schedule – to remove 60% of plant available water (FESW = 0.6)

		Month of year											
	Harvest date	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
	1 JUNE	13	13	14	16	DD			14	13	11	12	12
	1 AUGUST	12	13	14	16	20	24	DD			11	11	12
	1 OCTOBER	11	13	14	15	18	23	24	20	DD			11

(c) Dry schedule - to remove 70% of plant available water (FESW = 0.3) – (85% refill)

		Month of year											
	Harvest date	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
	1 JUNE	17	17	18	21	DD	(78)			18	16	16	17
	1 AUGUST	16	17	18	21	26	32	DD	(64)			16	16
	1 OCTOBER	16	16	18	21	25	30	34	28	DD			16

Assumptions:
- Refill of the profile is assumed to be 80% after each irrigation
- No rainfall
- Schedules based on averages of three soil characterisation sites (Innes, Lerch, Frank Wise)

13. SECOND SURVEY OF IRRIGATION PRACTICES

A second survey of irrigation practices was conducted in late 2000 and early 2001. The survey focussed only on irrigation management, unlike the initial survey in 1995-96 which included fertilising practices and other farm management inputs.

The main changes in irrigation practices that occurred in the 5 years between surveys were:

- A slight increase in the time period between irrigations.
- A reduction in the number of irrigations per year for some growers and little change for others.
- Significant reductions in the total amount of irrigation water applied by a few growers but little change for the majority of growers.
- A reduction in the duration of tail drain flow for most growers.

The survey was conducted prior to the release of the best practice irrigation guidelines at the April 2001 growers' workshop. Whilst the growers had been kept well informed of the results of the ongoing irrigation research, it was not until early 2001 that clear and unambiguous guidelines were released. Consequently it is not surprising that only a few growers had modified their practices before their release. We are aware of more substantial changes in irrigation practice having occurred in the period after the growers' workshop. In particular, growers have adopted longer periods between irrigations, fewer irrigations per year and less total water applied per year or per crop. A further survey of irrigation practices should be conducted towards the end of the follow-up irrigation project (CSE007) in 2005.

14. GENERAL DISCUSSION AND CONCLUSIONS

Research in this project has resulted in a number of significant and unexpected findings and has raised some important questions.

In all of the trials conducted there were no significant effects of drying-off on cane yield, Pol or Pol yield. This was a surprising result given the long drying-off periods of up to 80 days in some experiments. The reasons for the lack of response are not clear but it appears likely that at the time the drying-off treatments were imposed, cane yields were being limited by some unknown factor and that rates of crop water use at this time were relatively low. Based on the results from seven separate trials, drying-off does not appear to be an appropriate strategy in the Ord for increasing sugar concentration (Pol) in cane stalks. This is in contrast to the enhancement of sugar concentration or CCS often observed under Burdekin conditions, as described by Robertson *et al* (1999a). Consequently it is concluded that the drying-off strategy should only be used in the Ord for improving the trafficability of fields prior to mechanical harvesting and needs to be tailored to different soil types and to crop water use.

Similarly to the drying off trials, there was little yield or Pol response to the different irrigation treatments in the scheduling trials even though one treatment was fairly extreme in each trial. The only significant effect recorded at commercial harvest was a lower cane yield in the 180 mm pan evaporation treatment in the 1998-99 crop. The most severe water deficit treatment in the 1999-2000 crop also had a lower cane yield, Pol and Pol yield than other treatments although they were not significantly different. In general the yield reductions associated with extending the irrigation interval were not great when compared with the potential savings in water, labour costs and accessions to groundwater. However the two seasons when the trials were conducted (1998-99 and 1999-2000) had rainfall totals of 1145 mm and 1464 mm respectively which are well above the long term annual rainfall of 786 mm. It is concluded that less frequent irrigation strategies warrant further investigation particularly in the period following the wet season but the response to different irrigation schedules may be greater in drier years.

A significant finding from this project was that crop growth rates are considerably lower than those expected for sugarcane. Measurements of above ground biomass in the irrigation scheduling experiments showed rapid initial rates of crop growth until mid December (224 days after planting) for the plant crop and until early January (160 days after ratooning) for the first ratoon crop. However, after these samplings there was a substantial decline in crop growth rate. Comparisons with other areas show that early growth rates are not much lower than those measured in the Burdekin but later growth is significantly lower.

The factors contributing to this reduction in crop growth rate from early in the wet season are not known. Muchow *et al* (1995) has suggested that stalk death associated with lodging can cause a slow down in yield accumulation in high yielding, long duration crops in Queensland, although the observed plateau in yield accumulation usually occurs at a higher cane yield and later in the growth period, some weeks after lodging. However in the Ord, the slow down in growth appears to occur independently of lodging and independently of crop start date, as shown by the results from the plant, first and second ratoon crops in block 2B. Further investigation of possible causes is clearly needed.

Measurements of crop water use using EnviroSCAN equipment have shown that there is considerable variation during the growth of the crop. Water extraction by a sugarcane crop planted in May 1999 varied from a maximum of 10.9 mm/day during November to below 4mm/day from mid February onwards until harvest in June 2000. The evidence appears to suggest that there is a marked decline in crop water use to levels well below Class A pan evaporation during and after the wet season. This occurs in both long duration, high yielding crops that have lodged and shorter duration, lower biomass crops that stay relatively upright. Clearly there appears to be a close relationship between the pattern of crop biomass accumulation and the rate of crop water use, with a marked slow-down in both occurring following the onset of the wet season. These findings have important implications for irrigation water management recommendations with more frequent irrigations being appropriate during the hottest time of the year in the October – December period and relatively few irrigations being needed following the wet season. This is particularly important as the main period when accessions to the water table appear to be occurring is during and immediately after the wet season. This post wet season period, when the soil profile is usually well supplied with water, is a critical period for making sure that irrigations are conducted only if absolutely necessary.

Stalk elongation rates and pan evaporation losses are both used as indicators of when to irrigate sugarcane in parts of Queensland. These were tested as possible irrigation scheduling tools in the Ord but were found to support extremely frequent irrigations throughout the year which would most likely have resulted in the application of too much irrigation water. Clearly sugarcane crops in the Ord require the development of a special set of tools to assist the scheduling of irrigation.

A key finding from this project has also been the high soil water extraction capability of sugarcane grown on Cununurra clay soils. Characterisation of four of the main soil types occurring in the Ivanhoe Plain has shown that plant extractable soil water (PESW) ranged from 167 mm on the heavy Aquitaine soils to 226 mm on Cununurra clays in the central Ivanhoe Plain. Given the much lower than expected crop water use post wet season, these very high values for PESW provide additional support for longer intervals between irrigations but maybe for more water to be applied at each irrigation. The four soils investigated are all different in both PESW and depth of water extraction and so recommendations for scheduling irrigation across the irrigation area will need to be fine tuned according to soil type. The information on soil water characteristics for each soil type is an essential prerequisite for the use of the APSIM sugarcane crop growth model for analysing the consequences of different irrigation regimes in order to develop strategies for best practice irrigation management.

The APSIM-Sugarcane model has been used successfully in many environments to simulate crop biomass accumulation and crop growth rates. The preliminary work by Muchow and Keating (1998) to develop indicative estimates of irrigation requirements using the APSIM-Sugarcane model, using data available to them at the time, resulted in extremely high irrigation requirements approaching 40 ML/ha/year, assuming an application efficiency of 60%. This figure was supported by the high annual water applications used by the Ord growers and documented in the 1995-96 survey of irrigation practices. However the APSIM model is not configured for any reduction in growth rate, such as that observed in Ord sugarcane crops. Consequently APSIM-Sugarcane overestimated the biomass of the plant and first ratoon crops in the irrigation scheduling experiment in block 2B by as much as 40% and would also have significantly overestimated their irrigation requirements.

In order to rectify the problem the model was reconfigured, based on an analysis of the radiation use efficiency of these crops and the observations of Singh *et al* (2000) for crops which had lodged, to reduce the radiation use efficiency (RUE) to 1.0 g/MJ after the above ground biomass reached 30 t/ha. With these modifications APSIM Sugarcane simulated less growth during the later stages of crop development and the simulations followed the observed growth patterns more closely in the field-grown plant and first ratoon crops. The modified simulations also reduced the crop irrigation requirement by about 25%. Whilst the modified model describes the observed crop growth and biomass accumulation much more closely, further field investigation of the causes of the slow-down in crop growth is required before this phenomenon can be adequately represented in crop simulation models.

Improving irrigation water application efficiency is dependant on minimising the amount of water losses associated with run-off from irrigation bays and/or losses due to deep drainage from irrigation bays or from infrastructure such as channels and drains. Opportunities for improving efficiencies have been examined in other irrigation areas by using surface irrigation models such as SIRMOD. Irrigation application efficiencies were investigated for a number of furrow-irrigated bays of sugarcane on Cununurra clay soils in the Ord. Data collected from each bay were used with SIRMOD to simulate application efficiencies for each bay. Whilst the correlation between simulated and actual values for particular bays was quite good, it was found much more challenging to configure the model so that it simulated irrigation events in a range of irrigation bays in the Ord. A further challenge was to account for water infiltration rates associated with different furrow shapes, which can vary from a broad 'U' shape to a narrow 'V' shape. SIRMOD was eventually developed for general use in the Ord with both shapes of furrow. It was used to develop 'look up' tables indicating expected irrigation application efficiencies when such factors as moisture deficit, furrow inflow rate, irrigation duration, furrow length and furrow shape are varied. The look-up tables developed represent the most complete guidelines available for irrigators to use for maximising irrigation application efficiencies anywhere in the Australian sugar industry.

A comprehensive set of best practice irrigation guidelines which maximise profitability and minimise losses of water are now available to the Ord sugar industry. These include:

- Frequency of irrigation. This needs to be tailored to fit crop growth rate and crop water demand. Less frequent irrigations are required during early growth and more frequent irrigations during the hottest time of the year, particularly if the crop canopy is well developed. Very few irrigations are needed after the wet season due to the profile usually being filled with water during the wet season and because of the low crop water demand caused by the slow-down in growth. Soil water deficit should be used to schedule irrigations and irrigation frequency should also be varied for different soil types.
- Soil moisture at irrigation is extremely important. Irrigating into dry soil minimises tail water flow and lengthening the period between irrigations is the best way to increase water application efficiency. Sugarcane is less sensitive to irrigation regime than was previously thought and is better able to recover during the wet season from moisture stress caused by insufficient irrigation prior to the wet than many other crops.
- Tail water flow should not be allowed to run for too long and can be managed at different times of the year either by using different shut-off times or by varying siphon size. The duration of irrigation will depend on the time taken to wet up the soil around the cane plant. Often the soil surface never wets up but the soil below the surface can be quite wet.
- Furrow shape will affect the time taken to wet up soils. An irrigation will advance down a bay much more quickly with 'V' shaped furrows than with 'U' shaped furrows. Consequently the latter will provide greater infiltration, less tail drain flow and better application efficiencies. However in the wet season, when good drainage is needed, 'V' shaped furrows are more effective in draining surface water off the bay.
- Optimum row length. Longer row lengths will give better application efficiencies but poorer drainage and hence there is a trade off between the two. Shorter rows should be used on heavier soils to avoid waterlogging.

- Managing irrigations is much more difficult where deep drainage is occurring. Water losses in sandy areas require special management such as compacting on farm drains and channels. It is important to keep row lengths short in potentially leaky areas. Most deep drainage and accessions to the water table in the Ord appear to occur during and after the wet season when soil profiles are full of water.

Despite all this knowledge on best practice irrigation management the number of irrigations and the amount of water applied by Ord sugarcane growers did not show much of a reduction between the benchmarking survey conducted in 1995-96 and the 2000-2001 survey. However there have been marked reductions in irrigation water use amongst some of the larger growers for the 2002 crop. This may be because the research team had not presented the growers with a clear message on irrigation management until the workshop held in 2001. Prior to that the growers had been exposed to large amounts of research results, some of which conflicted with established practices, but no clear management recommendations. It was not until the irrigation workshop in 2001 that the research findings were fully interpreted and translated into clear and unambiguous irrigation guidelines. Had the second survey been conducted on water management for the 2002 crop, the results may well have been somewhat different. Nevertheless there remains considerable scope for growers to make further improvements to their irrigation management practices and tailor their applications more closely to the requirements of their crops, and it will not be until this occurs that regional water tables in the Ord will start to stabilise.

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ANALYSIS OF OUTPUTS AND OUTCOMES COMPARED WITH OBJECTIVES

All of the original objectives of the project have been identified. These were as follows:

1. Irrigation practices in the Ord Irrigation Area were benchmarked at the commencement of the project by means of a comprehensive grower survey. Any changes in practices were identified in a second survey conducted towards the end of the project. Whilst an industry workshop to define research priorities was not held, meetings to review research results and to plan further research were held twice yearly during the project and these allowed interaction between the research team and grower/industry representatives. Further review of research priorities occurred at Industry Board meetings, at Management Committee meetings for the Industry Development Officer and at the review conducted by SRDC.
2. On-farm and on-station research was successfully conducted to quantify the impact of different irrigation practices on productivity, water use efficiency and groundwater management. This research included drying-off experiments conducted both on-farm and on-station, irrigation scheduling experiments conducted on-station, soil characterisation conducted both on-station and on-farm, application efficiency measurements conducted mainly on-farm and measurements of crop water use and stalk extension conducted mainly on-farm. Direct analyses of the profitability of different irrigation practices were not conducted mainly because best practice irrigation management has only recently been defined. Some interaction has occurred between the Industry Development Officer and the Agriculture W.A. economist, Mr Francis Bright. It should be possible to quantify the water and labour savings associated with improved irrigation practices, although the environmental benefits of reduced accessions to the water table will be more difficult to quantify unless the costs of dewatering are used.
3. Sequential yield accumulation data was collected for the drying off experiments and for the irrigation scheduling experiments. Data from two automatic weather stations were also collected together with appropriate data on soils and crop management operations. These were all essential input data for the APSIM Sugarcane crop simulation model. The model, when used to simulate crop growth in the Ord, overestimated crop biomass and crop water use. Preliminary work to reconfigure the model with a reduced radiation use efficiency value for sugarcane with a biomass of >30 t/ha produced much better agreement between simulated and observed values for crop biomass. However further refinement of the model to tailor it for Ord conditions cannot really be done until the causes of the slow-down in crop growth are better understood.
4. Field experiments, databases and the APSIM Sugarcane simulation model have been used to help develop appropriate irrigation schedules for crops harvested or planted at different times of the year. The SIRMOD surface irrigation model has also been used to examine opportunities for improving water application efficiency and to develop a series of 'look-up' tables indicating expected irrigation application efficiencies when various parameters such as bay length, irrigation duration, inflow rate and soil deficit are varied.
5. Best practice irrigation management strategies have been developed and promoted by the project research team at Research Review and Planning meetings and at the 2001 Grower Workshop. The Industry Development Officer is responsible for ongoing promotion of industry best practice at field days, Industry Board meetings and grower workshops. A Best Management Practice booklet for the Ord, for distribution

to growers, is in preparation and this will include details of irrigation best management practices.

Additional objectives for the project that were raised at the SRDC project review were:

1. Appointment of an Industry Development Officer. This was achieved on 15th March 1999 when Mr Jim Engelke transferred to Kununurra.
2. Soil variation across the Ord irrigation Area was recognised. Soil surveys conducted in the area recognised four main soil types: Cununurra Clay alkaline phase, Cununurra Clay eroded phase, Aquitaine Clay and Packsaddle Sandy Loam (Aldrick *et al,* 1990; Stoneman, 1972). Four soils in the Ivanhoe Plain were characterised with respect to their plant available water content and the likely depth of water extraction by sugarcane.
3. The early work on irrigation water application efficiency identified considerable variation between cane blocks. Even though blocks were carefully selected for detailed study, it was still a challenge to configure the surface irrigation model SIRMOD so that it simulated irrigation events over a range of different blocks.
4. Possible nutritional limitations on productivity improvement were included with the investigations conducted by the Industry Development Officer. These included a survey of fertiliser use by growers and measurements of nutrient removal in harvested crops from different farms.
5. Growers and industry representatives were consulted regarding the timing of the project review and planning meetings. A strong preference was expressed for the meetings to focus on the presentation of research results and to be held before the season (March/April) and in November/December after the season was finished.
6. With less than 20 growers in the whole Ord sugar industry, the need to establish small focus groups of growers to facilitate the adoption of improved irrigation practices was not seen as a key objective. However the management committee set up to review the activities of the Industry Development Officer, with 2 grower members, 1 miller member, 1 CSIRO researcher and 1 from Agriculture WA, fulfilled the role of a small participative focus group.

POTENTIAL BENEFITS AND LIKELY INDUSTRY IMPACT

The following benefits are likely to arise from this project and impact on the sugar industries in the Ord and in eastern Australia:

- A better matching of irrigation applications to crop requirements leading to reduced use of irrigation water and reduced accessions to groundwater
- Improved likelihood of meeting future water licensing requirements and targets
- Reduced losses of irrigation water through deep drainage and tailwater runoff. This in turn results in a reduction in the amount of sediment, nutrients and agrochemicals leaving cane blocks. Deep drainage losses can be reduced once problem areas are identified using EM68 surveys and irrigation management practices are modified accordingly.
- Longer viability of laser levelled cane blocks and reduced siltation of tailwater drains.
- Improved profitability with less frequent irrigations through reduced irrigation costs (labour and water).
- Improved social impact through more leisure time and reduced stress. This can also be achieved by using SIRMOD to optimise the duration of irrigation events by changing bay lengths or siphon size thus reducing the necessity to turn off irrigation water in the middle of the night.
- Reduced pressure on irrigation infrastructure. More water available for additional land areas.
- Stabilisation of groundwater tables. Reduced need (and cost) for dewatering and other groundwater management strategies.
- Meeting targets of Ord Land and Water Management Plan such as improvements in water application efficiency, stabilisation of groundwater levels and improved water quality by reducing tailwater runoff. This will have the additional benefit of reducing pressures from environmental lobby groups.
- The results of this work will have direct benefits for other crops grown in the Ord such as cucurbits, chickpeas, sorghum and cotton. The look-up tables for improving water application efficiency will be applicable simply by altering the soil moisture levels required. Similarly the data from characterising different soils in the irrigation area will be applicable to irrigation management strategies for other cropping systems.
- Application of knowledge gained from this project will have positive flow-on benefits for other irrigated sugarcane areas such as the Burdekin.

RECOMMENDED FUTURE RESEARCH NEEDS

The following research needs to be undertaken in order to build on the major findings of this project:

1. A major research challenge is to find reasons for the dramatic slow-down in cane growth. Further growth analysis experiments need to be conducted, particularly in drier years and on lighter textured soils to investigate whether the slow-down in cane growth is related to poor drainage, waterlogging during the wet season and loss of nitrogen by denitrification. Specific sections of different crop stands need to be carefully tagged so that stalk numbers in the same stools can be monitored both before and after the wet season, to test the hypothesis of Muchow *et al* (1995) that stalk mortality coupled with lodging of the crop are major contributors to the plateauing in growth occurring in many high yielding sugarcane crops.
2. Crop growth also needs to be monitored in crops planted and ratooned at different times of the year so that a better appreciation can be obtained of the timing of the slow-down in growth in relation to crop size and so that appropriate irrigation schedules can be developed for different crop start times.
3. The impact of deliberately slowing down the early growth of crops through withholding irrigation water warrants investigation in order to find out the extent to which the crop can recover during the wet season and whether it can attain the same yield as a crop which had more rapid early growth. The degree of catch-up in yield during the wet season is likely to depend on the amount of rainfall received. Improved skills in forecasting the likely onset and severity of the wet season for the Kimberley region through the use of indicators such as the Southern Oscillation index and Sea Surface Temperatures would greatly assist with the management of irrigation schedules for the October to December period and could lead to substantial water savings and reduced accessions to the water table.
4. A major obstacle to improved profitability in the Ord is the lack of knowledge of how to improve CCS and juice purity, particularly early in the harvesting season. Reasons for the lack of CCS response to drying off need to be found. Also experimental work with chemical ripeners needs to be undertaken to find out whether improvements are possible in early CCS and juice purity.
5. The APSIM-Sugarcane model needs to be reconfigured for Ord growth conditions as the current method of reducing radiation use efficiency (RUE) after crop biomass exceeds 30 t/ha has little scientific basis except in lodged crops and is largely a way of achieving a better agreement between actual and simulated values for crop biomass.
6. The irrigation scheduling guidelines have not been adequately tested under commercial conditions in a range of different growing seasons. Further validation is required before growers can confidently adopt them for on-farm use. Similarly the look-up tables, based on soil water deficit, that have been designed to improve water application efficiency require further commercial validation.
7. The use of instrumentation on-farm is recommended to indicate the rate at which water is advancing down the bays. This will provide growers with greater confidence as to when to turn the irrigation water off and limit tail drain flows. The costs and benefits of tail water recycling should also be investigated as this is becoming a standard practice in some irrigation areas where water supplies are limited.
8. Areas where deep drainage is likely to occur need to be identified so that appropriate irrigation guidelines can be developed for these areas. Techniques are currently being investigated for mapping areas with a risk of deep drainage using EM31 and EM38 instruments and this work needs to continue.

Some of these research needs are being addressed in a new SRDC project (CSE007 - "Implementation of irrigation practices for profitable resource efficient sugarcane production in the Ord") that commenced in July 2002 and builds on the findings of this project. This new project aims to deliver the following outputs:

- Information for implementing best management practices for optimising productivity and mill performance
- Guidelines (rules of thumb) for best practice irrigation management developed, implemented and evaluated using an action research approach
- Benchmarks of irrigation practice for sugarcane production in 2002 and 2005 for evaluation of uptake of changed practices
- Better definition of water requirements of sugarcane growing in the Ord as an input to water allocation policy
- Processes based on action learning for implementation and evaluation of best practice irrigation management
- An economic database on Ord sugarcane production costs and drivers
- Model analysis of the economic and environmental consequences of different irrigation management strategies
- Better understanding of the physiological basis of yield accumulation for different growth stages and soil types under Ord climatic conditions as input to model analysis
- Explanation of atmospheric drivers of crop evaporation using Bowen ratio as input to model analysis
- Quantification of soil water extraction by sugarcane for different soil types as input to model analysis.

EXTENSION ACTIVITIES

The following extension activities have been conducted during the course of the project to discuss research objectives and to promote and discuss the data collected and the ways in which it can be interpreted.

Ord Sugar Industry Research Reviews

The Ord Sugar Industry has been closely involved in the project from its inception. Every time the project team meets in the Ord, at least one meeting to review research progress is scheduled, to which all growers are invited together with mill staff and other interested personnel. It has been usual for around 60-80% of growers to attend each of the meetings, which are held in the late afternoon. Throughout the project growers have been extremely interested in the results and have asked many probing questions. They have also made a significant contribution to the way in which the research has been conducted and also to the way the results have been interpreted.

The following topics were covered at the meetings:

November 1996: Improving nutrient management of sugarcane, recent advances in furrow irrigation and irrigation efficiencies, chemical and biological limits to sugarcane production.

March 1997: Groundwater management issues, findings from the grower survey of irrigation and crop management practices, update on crop logs, presentation on variety work and methodologies.

October 1997: History of sugarcane research in the Ord, variable pol in cane, unique climate of the Ord, research progress in irrigation management project.

May 1998: Overview of 1997 season and comparisons with 1996, presentation on irrigation management and plant extractable soil water, sugarcane nutrition in the Ord and new cane variety and pathology project.

August 1998: Smut outbreak, factors contributing to low pol, climatic conditions in 1998 and impacts of nitrogen on productivity and pol.

November 1998: Industry performance, mill operational issues and logistics, research into the reasons for low pol in the Ord, drying off and irrigation scheduling trials, proposed survey of grower fertilizing practices, and forthcoming grower benchmarking study.

April 1999: What is ccs? - implications of variation in fibre, brix and pol and varietal trends, possible causes of low pol in the Ord, factors affecting sugar yield on the Ord River, and developing nutrient management plans.

September 1999: Current research and extension activities, grower feedback on key issues, update on variety issues and progress on crop nutrition guidelines, update of results from the best practice irrigation project.

March 2000: Report on current extension activities including gappiness survey in plant crops and grower feedback on key issues, update on variety introductions and preliminary results from smut trial, report on results from the best practice irrigation project and possible interpretation of the crop growth and sugar accumulation data, and presentation on water use efficiency results and ways in which application efficiency can be improved.

November 2000: Overview of SRDC funding, update on irrigation research, related water research in Queensland including shallow groundwater work and irrigation risk management and crop water use in the Burdekin, Ord research to improve irrigation application efficiency, variety update, and smut and other research.

April 2001: Industry irrigation workshop (see below).

November 2001: Results from irrigation scheduling experiment in block 2B, update on progress with APSIM/grower treatments in irrigation trial in block 9A, review of mill commercial data (1996-2001).

Ord Sugar Industry Irrigation Workshop

A grower workshop was held with sugar industry representatives in the first week of April 2001 to examine ways of implementing local and other research findings relating to irrigation. Some notes taken at the workshop are given below:

Irrigation Best Practice for sugarcane production in the Ord Irrigation Area

Present:
Willem Bloecker, Andrew Kelly, Gordon Mock, George Gardiner, Fritz Bolten, Lindsay Innes, Peter Letchford, Ray Cummings, Greg Cummings, Rocky Lerch, Barry Lerch, Mike Moore, Jim Engelke, Joe Sherrard, Derk Bakker, Geoff Inman bamber, Gae Plunkett, Tim Triglone, Peter McCosker, Andrew Wood, Sarah Strutt (facilitator)

Objectives:
- To increase awareness of irrigation best practice
- To gain acceptance of irrigation guidelines as being practical
- To obtain a commitment by the growers to evaluate guidelines.

Review of previous research (Jim Engelke)
- Research over the last four years has shown no significant responses to different irrigation treatments or to drying off prior to harvest.
- Estimates of crop water requirements from the APSIM crop growth model are 22.6 – 31.5 ML/ha of applied water.
- The survey of irrigation water use conducted in 1996 showed that growers used 15.6 – 53.8 ML/ha of applied water
- APSIM crop growth model has been a useful tool for examining the consequences of different irrigation management strategies
- Measurements of yield accumulation have shown a distinct slow down in crop growth. The APSIM model has been reconfigured to fit the measured data
- Growth slow down means much lower crop water use for later growth period after wet season
- Irrigation guidelines suggest more frequent irrigations for early period of crop growth and less frequent irrigations after wet season
- Water use estimates based on pan evaporation together with pan factors could be used to schedule irrigations

Key messages: - Match water applied to crop demand
- Irrigation guidelines need to be tested in the field

Recap of current research guidelines (Joe Sherrard)
- Developing and implementing best practice for managing:
  - Irrigation application efficiency
  - Rising groundwater
  - Crop water requirements
- Tail water flow 3-4 hours minimum to fully wet up soil. Do not need to run tail water for too long.
- Lengthen period between irrigations to improve application efficiency.
- Water required for crop growth less than initially thought due to growth slow down
- Each hectare receives around 24 ML of irrigation and rainfall. Crop is only using around 17 ML/ha. Some of discrepancy is deep drainage.

Key messages: - Manage frequency of irrigation post wet
- Manage duration of tailwater flows
- Optimise deficit at irrigation
- Identify where deep drainage is occurring and minimise it

Discussion about research guidelines
- Management of tail water – different shut off times at different times of the year – unlikely to be adopted. May need to use different siphon sizes after wet season rather than having different shut off times
- Different amounts of biomass in block will affect advance rates

Key guidelines

a) From APSIM tables
- Watering less frequently after wet
- Watering more frequently during dry summer
- Watering more frequently for early cut crops prior to wet

b) From lookup tables from SIRMOD to optimise application efficiency
- Not letting tail water run for so long
- Flatten furrow shape (bed shape is independent of furrow shape and should be formed to minimise dirt in cane)
- Manipulating row length
- Alter siphon size to suit requirements
- Manipulating slope
- Irrigating onto drier soil

Comment: polyacrylamides assist subbing of water and could save a couple of irrigations

c) Other guidelines
- Use of soil moisture monitoring sites
- Knowledge of deep drainage (permeability mapping) allows people to manage accordingly such as keeping row lengths short in leaky areas
- Compacting on-farm channels and drains
- Liaise with Agwest / CSIRO staff for irrigation timing tables
- Manipulating crossfall to achieve more constant head in head channel

Discussion of opportunities presented by research guidelines
- Some easy to implement
- Others require major changes eg slope, run length
- There is no choice – Ord growers have to become more efficient users of water and will have to accept a reduced water allocation
- This workshop presents a good opportunity to revisit what we are doing

- We are going to have limited water allocations
- There will be rules that people will have to obey in order to limit groundwater accessions – licensing conditions and severe penalties
- Expectation in the community that change will occur
- There are good financial reasons for becoming more efficient
- Opportunity to identify inefficiencies in current practices by using APSIM model or other computer models or look up tables
- Likely to be licensing requirements to cut tail water by at least 50% - tail water recycling
- Public money should be provided to reduce leakiness of M1 channel and Diversion dam
- Community expectations must assist research funding
- Pursuing adoption of more efficient practices will help to lever more $'s for implementation
- Less run off means less silt going into drains. Would keep water costs down. Siltation of drains could lead to penalties to cover cost of cleaning them out.

Issues and problems that need to be addressed before implementing research guidelines:

- Translating research into something simple that can be used easily. Accessible tools for growers.
- Some farmers do not see change as a priority
- Tail water flows very difficult to manage and predict. How can we do it?
- Requirement by regulator to reduce tail water by 50%. Need to know on-farm where leaky areas are
- Limited knowledge of deep drainage – very difficult to quantify. Deep drainage is beyond the control of most growers. Need to factor this into water allocations unless it can be managed.
- Deep drainage likely to come more from rainfall than from irrigation
- To go to a new, higher level of management, we will need much better information. Use of SIRMOD, APSIM, evaporation measurement, soil type characterisation, measurement of deep drainage. "If you can't measure it then you can't manage it".
- Information needed at management scale (not just from 1one research experiment) in order to make better decisions
- Information we have now will allow some things to be done now. Other things will have to be done later on.
- Efficiencies need to be made in distribution system by Government instrumentalities. System will need to be 80% efficient – nowhere near this at present.
- Need to look at plant's ability to use water and soil's ability to hold it (organic matter, soil structure)

Workshop Groups

1. How do we translate research information into tools that are useful and accessible to growers
2. Tail water management

Actions from group 1 on tools

1. Provide simple tables with date of crop start based on past average conditions. These will include average time intervals between irrigations assuming no rain (will need corrections for rain). Calendar with suggested frequency of irrigations (choice of severity of water stress). **Action: Geoff by mid May**

2. Provide training in use of computer models to look at different scenarios either through Jim or for home use. Use model during wet season to look at different scenarios using real data. **Action: Jim to organise training session in mid November**
3. System for recording operational data to feed into model. **Action: Derk by mid May**
4. Better understanding of different soil types and influence they have on irrigation schedules. Interpretation of existing data on soil types to pick up which soil provinces exist and what guidelines apply. **Action: Joe and Jim collate and interpret what is currently known by mid May**
5. Make Sirmod look up tables available. **Action: Derk and Joe**
6. Produce a field guide for irrigated cane consisting of 2 laminated A4 sheets containing interpreted information from tables. **Action: Working group convened by Jim (Jim + grower + water person) by mid May**

Actions from group 2 on tail water

1. Eliminate algae from channels which blocks up siphons. **Action: Ord Irrigation Commission**
2. Implement field guide containing tail water recommendations. **See action 6 above.**
3. Investigate simple measuring devices to monitor start and finish times of tail water flows. **Action: Gae**
4. Investigate growth retardants to minimise lodging as this makes tail water monitoring very difficult. **Action: Jim**

Where to from here?

- Need to move towards Best Management Practice Guide for sugarcane.
- Ord Co-operative is prepared to help with the costs of producing and publishing this.
- Co-op can also help to fund the cost of providing loggers and better systems for monitoring tail water flow.
- Launch of guidelines at Field Day in mid June.
- Hold a mini workshop to assess progress on actions and to revisit other issues
- Notes from this workshop to be circulated.

Irrigation scheduling "Ute Guide"

A double page handout for sugarcane growers in the Ord was produced after the Irrigation Workshop to provide concise, practical guidelines for growers on irrigation schedules that meet crop water demands on different soils at different times of the year. The handout is attached in Appendix 2.

ACKNOWLEDGEMENTS

1. We wish to thank the following organisations which contributed financially to the work in this report:

- Sugar Research and Development Corporation
- CSR Ltd.
- Agriculture Western Australia
- CSIRO Sustainable Ecosystems (formerly CSIRO Tropical Agriculture)
- Ord River Canegrowers
- Ord Sugar Pty. Ltd.
- Cheil Jedang Ord River Sugar

2. We wish to thank all the cane growers in the Ord River Irrigation Area for the important role they played in the project and in particular for their enthusiasm for the project, their participation at project meetings, their completion of survey questionnaires and for willingly making land available on their farms for experiments and assisting with irrigation arrangements. In particular we wish to thank Peter Pegg, Rob Boshammer, Greg Cummings, Rocky Lerch, Lindsay Innes, Wilhelm Bloecker, Gordon Mock and George Gardiner who were closely involved with the experimental work.

3. We wish to thank the staff at the Ord Sugar Mill for their participation at project meetings, their assistance with harvesting arrangements of experimental sites and in providing crop productivity and pol data from the mill database. We particularly wish to thank Russell Kirk, Ben O'Reilly, Wayne Paul, Neill Farmer and Col Smith.

4. We wish to thank the technical staff at the Frank Wise Institute for their assistance with the field and laboratory work, Naomi Mackee of CSR Sugar for helping to set up procedures for juice analysis and Mike Spillman for his assistance in setting up the automatic weather stations and with field sampling techniques.

5. Many people have provided useful comments on the work presented in this report and have participated in helpful discussions. We particularly wish to thank Peter McCosker, John Leslie, Brian Keating, Peter Thorburn and George Gardiner.

INDUSTRY DEVELOPMENT OFFICER

Introduction and background

With the inception of the Ord Sugar Industry in 1995, it was decided that support for growers would be required. To address this issue, funding was initially made available by SRDC for an experienced extension officer from Queensland to service the Ord Sugar Industry. With the completion of this project in 1997, SRDC, the Ord Sugar Industry and the West Australian Department of Agriculture agreed to provide funding to employ a full-time Industry Development Officer (Sugar Agronomist) to service the research, development and extension requirements of the Ord. The position was first advertised in early 1998, re-advertised in late 1998 and eventually filled in early 1999 when Mr J.H. Engelke accepted the position. Mr Engelke commenced activities in the Ord in March 1999.

Range of activities 1999-2002

The industry established a list of activities to be undertaken by the Industry Development Officer. These included the following:

- Data management
- Irrigation
- On farm crop management
- Managing composition of cane supply
- Verification of research outcomes on farm
- Collation of information and communication

A key component of the position was management of the variety project. The discovery of smut disease in mid 1998 focussed national sugar industry interest on the Ord and the successful management of the disease. This issue occupied considerable time in managing and arranging necessary trials, reports and updates to the sugar industry. The smut screening work continues to operate in the Ord as an integral part of the variety introduction programme.

Regular reporting to the Sugar Agronomist Management Committee documents the range of activities in which the agronomist was involved. Being a new industry, a wide range of issues arose from the production of cane through to the processing environment. The End of Season reports provide a comprehensive list of activities that were undertaken during the 1999-2002 period.

Outputs and Industry outcomes

Many extension events occurred over the 1999-2002 period. These ranged from simple AgMemo articles through to detailed journal papers, research reviews and field days. These included:

- 1999 Workshop (x1)
- 1999 Field days (x2)
- 2000 workshop (x2)
- 2000 field days (x2)
- 2001 Workshops / Research Reviews (x2)
- 2001 Field Days (x2)
- Irrigation scheduling 'ute guide' developed.
- Commercial performance report – Analysis of mill data 1996-2001. J.H. Engelke.

- Conference Paper: *Field Responses to Irrigation in the Ord Sugar Industry*, by R.C. Muchow, T. Triglone, G.M. Plunkett, J.H. Sherrard, A.W. Wood and J.H. Engelke. Proceedings of the Australian Society of Sugar Cane Technologists 2001.
- Conference paper: *Sugarcane smut: successful management in the Ord*, by J.H. Engelke, B.T. Egan, J.H. Sherrard, T. Triglone and P.A. Jackson. Proceedings of the Australian Society of Sugar Cane Technologists 2001.
- Poster presentation: *Ord Sugar Industry Statistics*, by J.H. Engelke. Proceedings of the Australian Society of Sugar Cane Technologists 2001.
- Journal paper: *Improving irrigation for Ord sugarcane*, by J.H. Engelke, J.H. Sherrard, G.M. Plunkett and T. Triglone. Journal of Agriculture 2001.
- Posters: Ord Sugar Industry Marketing and Sugarcane Quarantine.

General discussions and conclusions

The Sugar Agronomist Management Committee (now renamed Research Development and Extension Committee) provided a strong base and clear direction for the agronomist position. The requests of the Committee and industry to a large extent were for investigative work to be carried out that provided an indication of how the industry was running. In many cases this did not necessarily involve classic research but rather information finding and reporting. Additionally, other more obscure issues such as nutrient mass flows through the sugar mill were required. The close working relationship between the miller and growers enabled rapid progress to be made on many issues without the interruption of any obstructive politics. It is particularly valuable when the mill, CJ Ord Sugar and previously CSR were only too happy to provide all information databases to facilitate investigations into crop production and quality to be performed and reported back to the entire industry.

Being a new industry, many issues arose that required input from an agronomic point of view. In addition, as the industry is small with relatively few people involved, the agronomist was able to provide an independent view on many issues that arose between the growers, miller and harvest / transport contractor.

Reports

End-of-Season reports for the 2000, 2001 and 2002 seasons together with an End-of-Financial Year report for the period 1999-2000 provide an outline of the various issues dealt with by the Industry Development Officer since March 1999. These are presented in Appendix 3.

Field Days

Five grower field days were held in November 1999, September 2000, July 2001, October 2001 and July 2002. Notes handed out at four of these field days are given in Appendix 4.

APPENDIX 1

PUBLICATIONS, REPORTS AND EXTENSION NOTES

Published Papers, Conference Papers, Reports, Field Day Notes, Ag Memos, Research Reviews and Research Workshops

Published Papers

Attard, S.J., Inman-Bamber, N.G. and Engelke, J.H. (2003) Irrigation scheduling in sugarcane based on atmospheric evaporative demand. Proc. Aust. Soc. Sugar Cane Technol. 25: on CD.

Engelke, J.H., Sherrard, J.H., Plunkett, G.M and Triglone, T. (2001) Improving irrigation for Ord sugarcane. Journal of Agriculture 42:45-50.

Gosnell, J.M. and Engelke, J.H. (2002) Development of a sugarcane industry in the Ord, Western Australia. Proc. S. Afr. Sug. Technol. Ass. 76: 110-119

Muchow, R.C., Horan, H.L. and Keating B.A. (2003) Developing irrigation guidelines for the Ord sugar industry using the APSIM sugarcane model. Aust. J. Exp. Agric. (In prep)

Muchow, R.C. and Keating B.A. (1998). Assessing irrigation requirements in the Ord sugar industry using a simulation modelling approach. Aust. J. Exp. Agric. 38: 345-354

Muchow, R.C., Triglone, T., Plunkett, G.M., Sherrard, J.H., Wood, A.W. and Engelke J.H. (2001) Field responses to irrigation in the Ord sugar industry. Proc. Aust. Soc. Sugar Cane Technol. 23: 109-115

Plunkett, G.M. and Muchow, R.C. (2003) Water extraction by sugarcane on soils of the Ord Irrigation Area. Aust J. Exp. Agric. 43: 487-495.

Wood, A.W., Muchow, R.C., Sherrard, J.H., Triglone, T. and Vogelsang, H. (1998) Benchmarking irrigation practices in the Ord sugar industry. Proc. Aust. Soc. Sugar Cane Technol. 20: 133-139

Conference and Workshop Papers

Bakker, D.M., Plunkett, G.M. and Sherrard, J.H. (1999) Improving irrigation water application efficiency in the Ord River Irrigation Area using computer simulation modelling. Irrigation 99 Conference, Perth, April 1999.

Sherrard, J.H., Robinson, C.J. and Plunkett, G.M. (1997) Groundwater management in the Ord Irrigation Area. Paper presented at ISSCT Sugarcane Irrigation Workshop, Townsville, September, 1997.

Sherrard, J.H., Engelke, J.H., Plunkett, G.M. and Triglone, T. (2001) Improving sugarcane irrigation in the Ord. Horticulture Program Workshop, Bunbury, September 2001.

Reports

Engelke J.H. (2001) Ord Sugar Industry, Report on Commercial Performance 1996-2001. Department of Agriculture, Kununurra. Report

Sherrard, J.H., Plunkett, G.M., Triglone, T., Bakker, D.M. and Engelke, J.H. (2002) Best practice water management for the Ord Sugar Industry. W.A. Dept. Agric. Internal Report, Research Activity Document, 95KU19.

Industry Board Reports: 1999, 2000, 2001, 2002

End of Season Reports: 2000, 2001, 2002

End of Financial Year Reports: 1999-2000

Sugar Check: Sugarcane Production on the Ord. Draft Best Practice Manual (in prep)

Field Day Notes

Field Day Notes – September 2000
Field Day Notes – July 2001
Field Day Notes – October 2001
Field Day Notes – July 2002

Irrigation Scheduling 'Ute Guide' (i) Sugarcane irrigation in the Ord – Guidelines; (ii) Irrigation scheduling for sugarcane : three harvest dates & two soil water deficits

AgMemos

Sugarcane smut update, February 2000
Biobusiness Farming School, February 2000
Smut update, May 2000
ASSCT 2000 review, May 2000
2000 sugarcane variety trial results, August 2000
Compost Field day, September 2000
Smut trial update, October 2000
Red Stripe / Top Rot in sugarcane, November 2000
Smut trial plant crop ratings, April 2001
Sugarcane plant stand quality (1999 & 2000), April 2001
Sugarcane bed profiles (2000), May 2001
ASSCT 2001 review, May 2001
Sugarcane variety trial results (plant cane – 2000 planted trial), September 2001
Irrigation trial in block 9A, August 2002
ASSCT Queensland visit, August 2002

APPENDIX 2

IRRIGATION SCHEDULING "UTE GUIDE"

SUGARCANE IRRIGATION IN THE ORD—GUIDELINES

Department of AGRICULTURE

CSIRO

Guidelines for Irrigation

⇒ Match crop irrigation to crop water demand

⇒ Extent of refill of the soil profile & soil type can influence scheduling

⇒ Soil water deficit is used to schedule irrigation

Soil water

Total potential Plant Extractable Soil Water (PESW) for sugarcane has been established to be in the range 169—225mm for soils of the ORIA (Table 1, column A).

The amount the soil profile is able to refill through irrigation is typically in the range of 75—85% of potential PESW (Table 1, column B).

Table 1. Calculates for three soil types with varying PESW, the amount of water available for plant use, assuming irrigation is scheduled at the point where 50% of total PESW remains for each.

	A	B	C	D
Soil Type	Total potential PESW	Plant extractable water after irrigation with 80% refill (A x 80%)	50% total potential PESW remaining at irrigation (A x 50%)	Water available for use by the plant (B - C)
1	169 mm	135 mm	85 mm	50 mm
2	190 mm	152 mm	95 mm	57 mm
3	225 mm	180 mm	113 mm	67 mm

Irrigation Scheduling

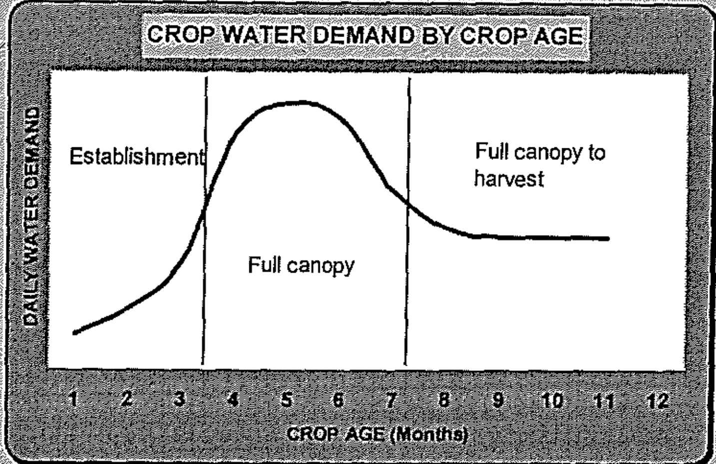
Scheduling of irrigation is performed by estimating when the crop has used the allowable amount of plant extractable water. Table 1, column D presents the amount of water available to the crop per irrigation, assuming irrigation is scheduled at the point where 50% PESW remains (Table 1, column C).

Irrigation schedules are presented on the reverse. The first assumes irrigation occurs when 50% of the total potential PESW remains (Table 1, column C) and the second when 40% of the PESW remains (A x 40%).

Crop water demand

Crop water use can be separated into three distinct phases;

1. Harvest to canopy closure
2. Full canopy (All green leaves)
3. Full canopy to harvest



IRRIGATION SCHEDULING FOR SUGARCANE THREE HARVEST DATES & TWO SOIL WATER DEFICITS.

Irrigation intervals are presented in days for each month in the tables below.

ASSUMPTIONS & EXPLANATORY NOTES

- Refill of the soil profile is assumed to be 80% of the total potential plant extractable soil water after each irrigation.
- Irrigation scheduled after either 50% (Table A) or 40% (Table B) of total potential PESW remains in the soil profile.
- Assumes no rainfall, therefore need to modify intervals when rainfall occurs.
- Schedules are based on an average of the three soil types presented in Table 1.
- Long term average climatic data has been used to establish irrigation schedules.

DD = Dry Down prior to harvest

The three months after harvest have no entries as no real data are available (2001 irrigation trial examining this period).

TABLE A: 50% of plant extractable water remains.

HARVEST DATE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1 JUNE	**14**	**14**	**14**	**15**	**DD**				**8**	**7**	**7**	**12**
1 AUGUST	**9**	**12**	**12**	**14**	**17**	**19**	**DD**				**7**	**7**
1 OCTOBER	**8**	**8**	**9**	**12**	**16**	**18**	**18**	**18**	**DD**			

TABLE B: 40% of plant extractable water remains.

HARVEST DATE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1 JUNE	**16**	**16**	**18**	**18**	**DD**				**11**	**9**	**9**	**14**
1 AUGUST	**11**	**16**	**16**	**18**	**21**	**25**	**DD**				**9**	**10**
1 OCTOBER	**11**	**11**	**11**	**16**	**20**	**24**	**25**	**25**	**DD**			

APPENDIX 3

INDUSTRY DEVELOPMENT OFFICER END OF SEASON REPORTS

END OF FINANCIAL YEAR REPORT, 1999- 2000

Jim Engelke
Sugar Agronomist, Kununurra

Data management

CSR Data bases

Obtained copies of previous years mill databases and set up for long term analysis purposes.

Irrigation & Stalk elongation

Stalk elongation measurements were taken on 3 paddocks during late 1999. (Q96 plant Cummings, Q96 plant Bothkamp, Q99 1R FWI)

Q96 Cummings also looked at the relationship of stalk elongation in relation to available soil water.
Results presented to industry December 1999.

Assisted G. Plunkett in identification and establishment of DUL / DLL sites in ORIA>

Nutrition

- Nutrient movement through the mill.

A summary of the nutrient quantities exiting the mill is attached. These figures have been established by chemical analysis of mill mud and ash exiting the mill. More work is required to better understand what nutrients are plant available and the variation throughout the year.

Calcium response trial established on Oasis Farms.

Gappiness Survey

- Plant cane gappiness survey completed and data compiled and presented to industry December 1999.

Dirt in cane (Bed profile survey)

Results of the bed profile survey on plant cane compiled and presented to growers December 1999.

Verification of research on farm

Dual row / single row (Oasis)

- Two counts of the number of tillers/stalks per metre were carried out on Q99 dual row and single row cane. Next count harvest 2000.

Results presented to industry December 1999.

Cane Variety Issues

Observations of Q96 in the valley has seen the ratoons not looking healthy. Typically there are a number of stools which are doing well and others which have died and other not performing well.

Established that Q96 is recognised for its sensitivity to harvester damage. (review of literature, inspection of affected paddocks)

Cummings Q96 sampling over time for pol and fibre accumulation.(early 2000).

Letter written to South Africa requesting access to cane varieties.

Planting Frank Wise paddock 9A.

Smut Issues

- Smut trial establishment 1st September 1999.
- Smut survey completed for the ORIA. Smut detected at Packsaddle in Nco-310 and Q96.

Approximately 460 hectares has been plough out during 1999. Search of cane carried out.

Nutrition

- Sulphur Calcium trial established, Lerch
- Cane Nutrient removal. Data collected from irrigation trial cane FWI.
- Deep soil nitrogen survey.
- Ash Analysis results obtained.

No evidence was established of any deep soil nitrogen in either nitrate (NO3) or ammonium (NH4) forms. Testing was carried out over 10 sites throughout the Ord River Irrigation Area to a depth of 2 metres.
Results were presented to the sugar industry September 1999.

Collation of Information and Communication

Workshops

1. Research review Presentation, September 1999.
2. Sugar Field Day / Update, December 1999.
3. Sugar Mill By product processing Field Day 1st September 1999.
4. Bio Ag soil seminar.

Field days / demonstrations

1. Kununurra Agriculture Show, Sugar Industry Display.
2. March Research Review
3. Sugar Industry Poster for Horticulture Review.

Media

1. Report for the Round the Mill publication (x2).
2. Ag Memo articles (x5). (Topic: 2 x Smut updates, ASSCT 2000, Bio Business School Feb 2000, China visit).
3. Article for the Primary Focus (x2).(Topic: China, smut)
4. Muresk Messenger (x1)

5. Australian Sugarcane Magazine (x1) (Topic: Smut in the ORIA).
6. ABC Radio interview with Greg Hayes, Kununurra (Topic: Smut)
7. ABC Radio Interview with Naomi Morison, Country Hour, Perth (Topic: Sugar Industry)
8. ABC radio interview on Ord Sugar Industry (general).
9. Numerous visits to sugar growers in the ORIA.

Information maintain broad overview

Initiated sugar cane manual to review and summarise relevant literature and information for Ord cane industry.

Attended ASSCT conference Townsville, April 1999.

Industry Board Requirement for information

Provided information to Canegrowers meeting on several occasions.

Other

- Glyphosate Damaged cane Bloecker.
  Report completed.
- Leslie and Blyth report completed and submitted to industry November 1999.
- Visit to Chinese sugar industry (Jan 2000)
- Prepared end of season report (November 1999).
- Completed Log frame, Horticulture Program Agriculture W.A.
- Support for compost trial on 318 throughout 1999.
- Quarantine protocol pursued and completed.
- R. Lethbridge clearing proposal
- K. Skerman soil maps/type information for subdivision application.
- Assisted in sorting issues involved with the planting of 9A.
- A & S Mason. Paw –paw and banana inter-row cover crop trial.
- CSR Mill induction.
- Darryl Deacon supply information for teaching purposes.

END OF SEASON REPORT 2000

Jim Engelke
Sugar Agronomist, Kununurra

The following report is a summary of what occurred in Extension, Research and Development over the 2000 season. The report is separated into the three headings Extension Research and Development. The list relates to major activities of the Sugar R,D, & E through out the year.

Extension: Collation of Information and Communication

Information maintain broad overview

Initiated sugar cane manual to review and summarise relevant literature and information for Ord cane industry.
Attended ASSCT conference Bundaberg, May 2000.

Industry Board Requirement for information

Provided information to Canegrowers meeting on several occasions.

Workshops

1. Farming For Profit, February
2. Bio Ag soil seminar.
3. Nutritech soils seminar

Field days / demonstrations

1. Kununurra Agriculture Show, Sugar Industry Display. (Sugar Industry poster & Compost poster).
2. March Research Review
3. Sugar Industry Poster for Horticulture Review.
4. Compost field day 31st August.
5. Smut trial field day 14th September
6. Weed control field day (IAMA) 16th November
7. November Research review.

Media

1. Ag Memo articles (x8). (Topic: 4 x Smut updates, ASSCT 2000, China visit, Variety Trial results, Red stripe/Top rot).
2. Article for the Primary Focus (x1).(Topic: China)
3. Muresk Messenger (x1)
4. Sugarcane ORIA (Nitrogen, Cane Quality Measurement, Variety trial results, South African Link, Smut booklet).
5. Australian Sugarcane Magazine (x1) (Topic: Smut in the ORIA).
6. ABC Radio Interview with Naomi Morison, Country Hour, Perth (Topic: Sugar Industry)
7. ABC radio interview on Ord Sugar Industry (general) August.
8. Zimbabwean Farmer tours (x2).
9. Mozambique sugar industry representatives tour.
10. Qld politicians tour of mill / ORIA valley.
11. Jerry Gosnell, South African agronomist tour of valley.
12. Numerous visits to sugar growers in the ORIA.

Research: Data management

- Discussions with Horticulture Program manager (T.Hill) regarding funding availability for purchase of new wholestick planter and fertiliser rig. Two items purchased.
- Enquiries regarding the purchase of a weigh bin. Funding issues to be resolved.

Irrigation

- Assisted G. Plunkett in the site selection and grower approval for establishing Drained Upper Limits / Crop Lower Limits in various soil types in the ORIA. Four DUL and three CLL were established for the ORIA. (One on FWI not included).
- First ratoon crop successfully harvested and processed.

Cane Variety Issues

- Varity trial (R.V.T 1) harvested and results analysed. Three canes distributed for further 'on farm evaluation'.
- Variety trial (R.V.T. 2) planted using smut trial results. Establishment successful.
- Introduction of 39 new canes into open quarantine (levee block).
- The new quarantine proposal for cane introduction reducing glasshouse time from 2 years to one year approved and finalised.
- Currently in the process of seeking approval to place canes destined for the ORIA into the glasshouse facilities in Townsville rather than Brisbane in order to reduce costs.
- Letter written to South Africa requesting access to cane varieties. Response received. Decision to be made on import possibilities.
- Sent leaf material of 'Q125' to Queensland for verification of variety through DNA testing. No results from testing to date.
- Ripener trials on late cut Q99. No response detected.

Smut Issues

- Smut trial one completed. Plant and ratoon ratings compiled.
- Smut trial two planted July 2000. Final plant rating to occur early 2001.
- Survey of selected commercial blocks of cane. Results support findings of smut trial one.
- Australian Society of Sugarcane Technologists (A.S.S.C.T) paper on smut issues/progress in the ORIA currently being finalised.
- Smut whip collection for BSES analysis purposes. Analysis performed in Canada for strain differences. Results not yet available.

Development: Verification of research on farm

CSR Data bases

- Obtained copies of previous years mill databases and set up for long term analysis purposes. 2000 database yet to be obtained.

Cane Agronomy Issues

- Cummings Q96 sampling over time for pol and fibre accumulation.(early 2000).

- Hot water treatment plant operates for the first time. Treated a single batch of cane.
- Monitoring the performance of three canes distributed for further evaluation MQ88-2047, Q125 and Q155.

Irrigation & Stalk elongation

- Stalk elongation work was pursued (G. Plunkett) on 3 blocks in the valley in conjunction with soil water information obtained using a 'Diviner'. Work is showing that stalk elongation can be maintained through more frequent irrigation, however, cane appears to be able to compensate if not water so frequently.

Nutrition

- Nutrient movement through the mill. Estimations of masses of various nutrients exiting the mill in by products.
- Sodium mass flow carried out on ash water return system utilised at the mill. Concluded that it is feasible that elevated levels of sodium are a result of concentration.
- Nutrient removal determined for 5 paddocks in the ORIA. Sample analysis to be completed.
- Leaf analysis data collection initiated. Approx 10 paddocks assessed for leaf nutrient status. Aim is to collate information on crop nutrient levels to more fully understand cane growth in the ORIA.
- Obtained current fertiliser practice from eight growers in the ORIA. Using information to establish fertiliser costs and range of practices.

Gappiness Survey

- Plant cane gappiness survey carried out on 2000 plant cane and to be data compiled and presented to industry.
- Weed pressure has appeared to increase from 1999 season. If this year is any indication of future trends weeds and in particular grasses, are likely to become a significant issue.

Dirt in cane (Bed profile survey)

- Results of the bed profile survey on plant cane to be compiled and presented to growers. Generally bed profile looking more suited to harvesters requirements, still opportunity for improvement.

Dual row / single row (Oasis)

- Tiller / stalk counts completed on the single and dual row Q99 planted on Oasis farms. Little difference in final stalk numbers at harvest. Harvest results inconclusive. Continue to monitor the crops performance into ratoons.

Nutrition

- Sulphur trial (Lerch) harvested. Results indicate no obvious advantage from additional sulphur.
- Cane Nutrient removal. Five blocks of cane sampled and to be analysed for nutrient removal. Testing yet to be completed.
- Ash Analysis performed and results obtained.
- On farm potassium trial established (Cummings) on 5th ratoon cane.

- Assisted in examination of options for by mill by product disposal. (Composting vs incineration)

Other

- Visit to Chinese sugar industry (Jan 2000)
- Completed Log frame, Horticulture Program Agriculture W.A.
- Support for compost trial on 318 throughout 2000.
- Quarantine protocol for introducing new cane varieties pursued and completed.
- R. Lethbridge clearing proposal
- K. Skerman soil maps/type information for subdivision application.
- Assisted in sorting issues involved with the planting of 9A.
- A & S Mason. Paw –paw and banana inter-row cover crop trial.
- CSR Mill induction.
- Darryl Deacon supply information for teaching purposes.

External part time study

Post graduate study in Graduate Diploma Business (Agriculture) will be completed by mid 2001.Options include

1. Cease external study or
2. Continue into studying a Masters of Business.

Approval is sought from the Agronomist Management Committee to continue with a Masters if that decision is taken over the next 12 months.

END OF SEASON REPORT 2001

Jim Engelke
Sugar Agronomist, Kununurra

The following report is a summary of what occurred in Extension, Research and Development over the 2001 season. The report is separated into the three headings Extension Research and Development. The list relates to major activities of the Sugar R,D, & E through out the year.

Extension: Collation of Information and Communication

Information maintain broad overview

Initiated sugar cane manual to review and summarise relevant literature and information for Ord cane industry.
Attended ASSCT conference Mackay, May 2001.
Two papers presented from the Ord, Smut and Irrigation paper.

Industry Board Requirement for information

Provided information to Canegrowers and Industry Board.

Workshops

1. Irrigation workshop, April 2001.
2. Edited and compiled Kununurra Horticulture Review papers, August 2001.
3. Beef conference, Meeting Market Specifications, November 2001.

Field days / demonstrations

1. Kununurra Agriculture Show, Sugar Industry Display. (Sugar Industry poster & Compost poster).
2. General sugar field day, July 2001
3. 3 x Posters on sugar industry for Horticulture Program Review, September 2001.
4. General sugar field day, 9A, October 2001
5. November Research review.

Media

1. Ag Memo articles (x2). (Topic: 2 x Smut updates, ASSCT 2001, Variety Trial results).
2. 2 x papers published in the ASSCT 2001 proceedings.
3. 1 x paper published in Journal of Agriculture.
4. ABC Radio Interview with Greg Hayes, Kununurra (Topic: Sugar Industry)
5. Jerry Gosnell, South African agronomist tour of valley.
6. Numerous visits to sugar growers in the ORIA.

Research: Data management

- Weigh bin received May and used in 2001 season.

Irrigation

- Purchased and installed a second Enviroscan (cane water use)
- Second ratoon crop successfully harvested and processed.

Cane Variety Issues

- Varity trial (RVT 1) first ratoon harvested, results analysed and distributed. Three canes previously distributed for further 'on farm evaluation' bulked up on various farms.
- Variety trial (RVT 2) plant crop harvested, results analysed and distributed. Establishment successful.
- Modified cane introduction protocol to enable introduction of new canes direct from BSES glasshouses, Indooroopilly, Queensland.
- Assisted in the access to overseas varieties held by BSES.
- Introduction of 96 new canes into open quarantine (levee block).

Smut Issues

- Smut trial two completed. Plant and ratoon ratings compiled results distributed Nov 2001.
- Smut trial three planted May 2001. Final plant rating to occur early 2002.
- Survey of selected commercial blocks of cane. Results support findings of smut trial one. Commercial planting of 2002 not recommended.

Development: Verification of research on farm

Mill Data bases

- Obtained copies of previous years mill databases and set up for long term analysis purposes. First draft of report completed Nov 2001.

Cane Agronomy Issues

- Inspection of Q96 indicates smut disease pressure increasing. As a result recommendation that no commercial planting of Q96 in 2002. However, recommended that clean short hot water treated seed plots established.
- Monitoring the performance of three canes distributed for further evaluation MQ88-2047, Q125 and Q155.
- Examined reasons for yield depression in 2001.
- Weeds continue to cause significant problems in many field of cane in the Ord.

Nutrition

- Nutrient removal determined for 5 paddocks in the ORIA. Sample analysis to be completed.
- Leaf analysis. Approx 30 paddocks sampled for leaf nutrient status. Aim is to collate information on crop nutrient levels to more fully understand cane growth in the ORIA. Results available early 2002.
- Obtained current fertiliser practice from eight growers in the ORIA. Using information to establish fertiliser costs and range of practices.

Dirt in cane (Bed profile survey)

- New butt lifter trial abandoned due to harvest contractor removing it from the machine before trialing was possible.

Dual row / single row (Oasis)

- Greater number of stalks counted in the dual row in the first ratoon crop. However no yield difference.

Nutrition

- Cane Nutrient removal. Five blocks of cane sampled and to be analysed for nutrient removal. Testing yet to be completed.
- On farm potassium trial harvested (Cummings) on 5^{th} ratoon cane. No yield or pol difference detected between treatments.

Other

- Completed Log frame, Horticulture Program Agriculture W.A.
- Support for compost trial on 318 throughout 2001.
- Quarantine protocol for introducing new cane varieties pursued and completed.

External part time study

Post graduate study in Graduate Diploma Business (Agriculture) completed 2000. Upgraded to a Masters of Business Administration (MBA) through the University of New England. Study will be completed end of 2002. Application for Department of Agriculture assistance has been lodged with the Regional Director, Dr Paul Novelly.

END OF SEASON REPORT 2002

Jim Engelke
Sugar Agronomist, Kununurra

The following report is a summary of what occurred in Extension, Research and Development over the 2002 season. The report is separated into the three headings Extension Research and Development. The list relates to major activities of the Sugar R,D, & E through out the year.

Extension: Communication, facilitation and implementation

Information maintain broad overview

- Initiated sugar cane manual to review and summarise relevant literature and information for Ord cane industry.
- Attended ASSCT conference Cairns, April 2002.
- Visited the offices of the BSES (Mareeba, Brandon, Mackay, Brisbane) Impressed with the bio-tech programme.
- Attended SASTA conference in July / August 2003. Impressed with ripener work developments.

Industry Board Requirement for information

Provided information to Canegrowers and Industry Board.
At request of Industry Board compiled Sugar Check (Draft stage)

Workshops

- Facilitated KPIA board meeting.

Field days / demonstrations

- 2 x 15 minute field days (9A irrigation updates & variety).
- Research Review, April 2002.
- November Research review 2002.

Media

- Ag Memo articles (x3). (Topic: 1 x Smut updates, ASSCT 2002, Variety Trial results).
- 1 x paper published South African Association of Sugar Technologists.
- Numerous visits to sugar growers in the ORIA.

Research: Data management

Irrigation

- Purchased and installed a third Enviroscan (cane water use) for on farm demonstration purposes.
- First ratoon 9A crop successfully harvested and processed.

Cane Variety Issues

- GxE trial harvested and data send to Queensland (no report available to date)
- Variety trial (R.V.T. 2) 1R crop harvested, results analysed and distributed.
- R.V.T 3 established (6 series)

- Received another batch of overseas canes from BSES glasshouses, Indooroopilly, Queensland.
- Introduction of 96 new canes into open quarantine (levee block).
- Short hot water treated some Q96 (Oasis farms / Frank Wise) for use as plant material in 2003.

Smut Issues

- Smut trial 3 completed. Plant and ratoon ratings compiled results distributed Nov 2002.
- Smut trial 4 planted August 2001. Final plant rating to occur early 2003.
- Survey of selected commercial blocks of cane. Results support findings of smut trial 1, 2 and 3, with the notable exception of Mida. Recommendation for Mida remains that no commercial scale planting occurs.

Development: Verification of research on farm

Mill data bases

- Databases continue to be an important source of information for millers, growers and researchers. Mill management request large amounts of material accessible through the database system.
- Compiled 2002 data into suitable format after W.Paul supplied the relevant databases. Yet to add 2002 data into the main database including all years. (Block paddock number changes make this difficult)

Cane Agronomy Issues

- Examination of root growth in plant cane has shown poorer that expected root system development. This was evident in both plough out replant and cane planted to virgin soil (Ex leucaena)
- Wire worm damage detected in late planted cane (Mirrawong farm – Waugh & Dwyer)
- Data collection on soil temperatures (10mm and 50-75mm). Consitiuted part of the poor germination and root development investigations.
- Inspection of Q96 indicates smut disease pressure increasing. No commercial planting of Q96 unless plant material has been short hot water treated.
- Varieties Mida, Q125 and Q155 only constitute emergency canes, unlikely to be released for commercial production..
- Contributed to Ross Ridge report on 2001 season yield issues.
- Weeds continue to cause significant problems in many field of cane in the Ord.

Nutrition

- Nutrient removal determined for 5 paddocks in the ORIA. Sample analysis to be completed.
- Leaf analysis. Approx 30 paddocks sampled for leaf nutrient status. Aim is to collate information on crop nutrient levels to more fully understand cane growth in the ORIA. This continues from work started 2001. Results available early 2003.

Dual row / single row (Oasis)

- Greater number of stalks counted in the dual row in the first ratoon crop. However no yield difference.

Other

- Completed Log frame, Horticulture Program Agriculture W.A.
- Support for compost trial on 318 throughout 2001.
- On the by product disposal committee looking for options to dispose of excess mill bagasse, mud and ash.

Study

Lodged application for funding from the SRDC for funding to pursue PhD studies

Comments

Less was achieved in the position this year largely due to illness early in 2002.

Leaving position in January / February 2003.

APPENDIX 4

INDUSTRY DEVELOPMENT OFFICER FIELD DAY NOTES

ORD SUGAR INDUSTRY

FIELD DAY NOTES

SEPTEMBER 2000

IRRIGATION

Soil characterisation
Crop water use Block 27
Irrigation trial results – Plant and I ratoon summary of results

VARIETY UPDATE

Replicated Variety Trial I – Plant results
Smut trial I – Plant & I ratoon results

Jim Engelke, Joe Sherrard, Gae Plunkett, Tim Triglone
Department of Agriculture
Sugar Research, Development & Extension
Kununurra WA

14/9/00

SUGAR CANE – CROP WATER USE

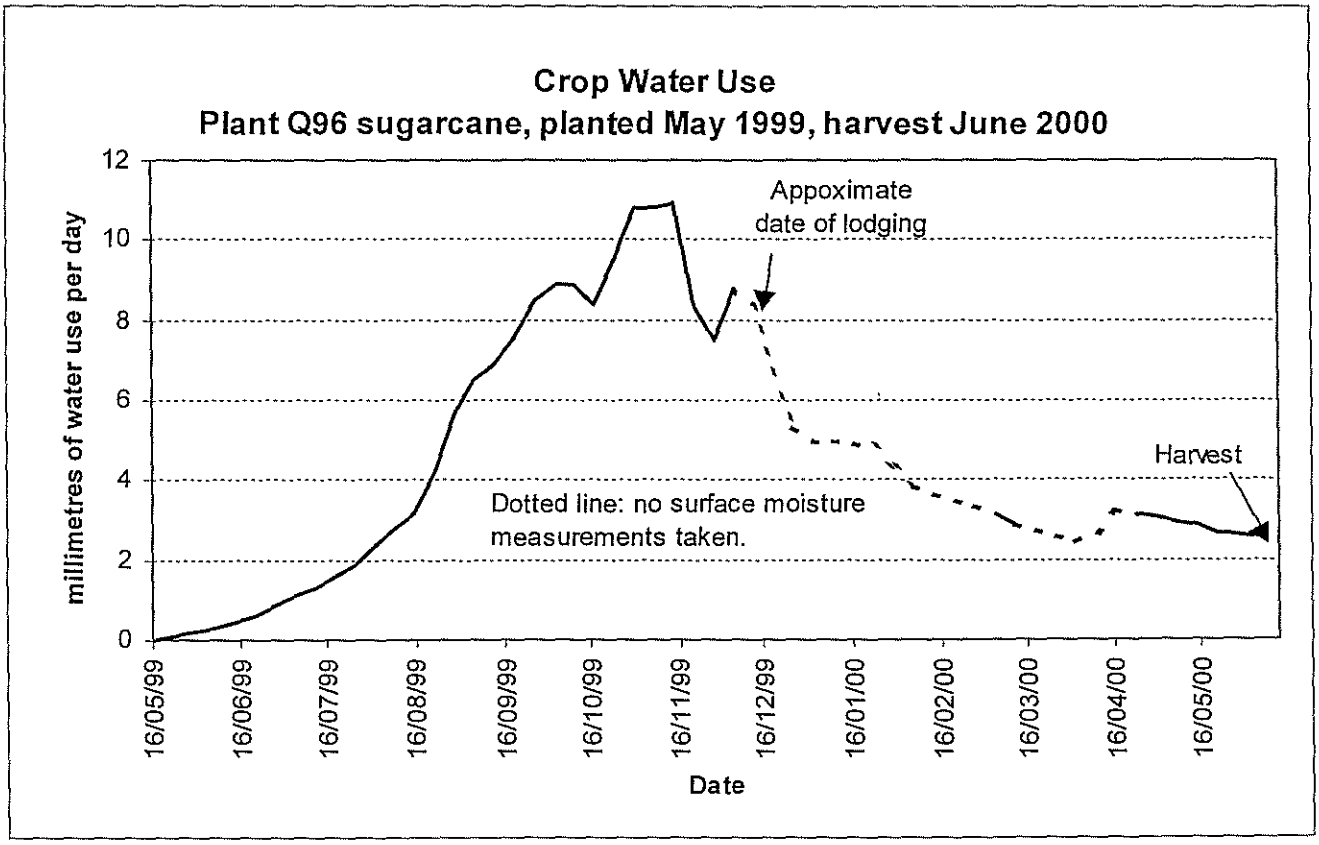
A series of sites around the valley have been selected to establish the total water holding capacity of the soil (Drained Upper Limit) and the amount of remaining after sugarcane has removed the available water (Crop Lower Limit).

The table below provides in millimetres the water present in 1 metre of soil (Drained Upper Limit) and the water remaining after extraction by sugarcane (Crop Lower Limit). The difference is the amount of water removed by sugarcane.

	Cununurra clay	Aquitaine clay
Drained Upper Limit (Total water, mm)	388	525
Crop Lower Limit (mm)	268	381
Crop Extraction (DUL – CLL, mm)	120	144
Days taken for sugarcane to remove water.	129	68

Crop Water Use Plant Q96

Using a combination of a Diviner (electronic) and the Neutron Moisture Meter measurements estimates of a crop water use have been made.



Assumptions and points of interest

Assume the change in soil moisture at 20cm is the same as for 0-20cm.

The evaporation rate over the period May 99 – Jun 00 was approximately 20% below the long term average.

Total crop water use has been estimated to be in the vicinity of 17 megalitres

The estimate of total water applied via irrigation to this crop was 14.5 megalitres per hectare (13 irrigations). Of the 14.5 megalitres applied it is estimated that 7-10 megalitres of this was used by the crop.

VARIETY TRIAL RESULTS (MAY 2000) Plant Cane

The 1999 variety trial was planted prior to information being available on the varieties level of smut resistance / susceptibility. As a result there are varieties in the trial that will be of little no commercial use based on smut susceptibility.

BRIX = Total soluble solids in juice
CCS = Commercial Cane Sugar
TCH = Tonnes Cane per Hectare
TSH = Tonnes Sugar per Hectare

VARIETY	BRIX	CCS	FIBRE%	TCH	TSH	
MQ88-2047	18.8	13.2	14.9	187.5	24.66	**
PELORUS	18.8	12.8	15.8	189.2	24.22	
Q127	18.5	12.7	15.6	190.4	24.11	
Q96	20.2	12.4	19.9	187	23.20	
KQ91-20301	19.6	13.6	18.9	165.8	22.59	
KQ88-8075	19.2	13.7	15.2	162.7	22.32	
Q99	18.1	11.6	14.6	192.2	22.28	
MQ74-110	16.6	11.8	13.5	186.7	21.98	
Q155	16.7	12.6	14.7	171.1	21.57	**
Q125	17.1	11.9	14.2	172.6	20.54	**
ORPHEUS	19.1	12.4	14.6	163.9	20.25	
BMQ89-15	17	10.2	15.3	193.2	19.79	
Q138	16.4	10.9	16.4	179.1	19.57	
KQ91-31405	16.8	10.6	15.2	177.8	18.82	
BMQ89-77	18.3	12.3	18.8	152.2	18.75	
Q142	16.9	9.8	14.9	188.1	18.47	
Q122	19.4	12.0	18.1	153.5	18.38	
89-518-6	15.8	10.0	14.0	180.8	18.10	
MQ97-155	14.5	9.0	14.5	200.8	18.01	
89-503-10	16.6	10.1	14.2	175.7	17.71	
KQ91-31506	16.6	9.9	13.9	178	17.58	
Q161	14.6	9.6	13.5	181.4	17.48	
89-680-3	15.6	9.8	16.3	174.5	17.03	
BMQ89-14	14.4	8.7	13.7	184.8	16.17	
MQ79-141	16.3	9.4	15.9	163.7	15.43	
Q124	15.2	8.7	12.4	165	14.28	

** indicates varieties selected for further evaluation "on farm".

SMUT TRIAL RESULTS Latest inspection carried out 6th September 2000

Results include the last rating of the plant crop (3/4/00) and the latest for the first ratoon crop (6/9/00)

VARIETY	Plant 3/04/00	1R 6/09/00
89-247-5	4.2%	0.0%
89-393-1	0.0%	0.0%
89-393-3	0.0%	0.0%
89-503-10	41.9%	0.0%
89-518-6	0.0%	0.0%
89-680-3	2.8%	0.0%
89-680-6	0.0%	0.0%
H73-6110	0.0%	0.0%
MQ80-805	0.0%	0.0%
MQ88-2022	0.0%	0.0%
MQ88-2047	8.3%	0.0%
Q125	0.0%	0.0%
Q130	0.0%	0.0%
Q155	0.0%	0.0%
Q95	1.6%	0.0%
Q99	0.0%	0.0%
Q142	0.0%	3.1%
90-83-5	2.8%	3.6%
KQ91-31405	48.4%	7.8%
ORPHEUS	14.6%	9.4%
KQ91-31508	41.7%	10.6%
CP74-2005	12.9%	11.1%
Q145	21.2%	14.1%
90-77-5	16.9%	15.7%
H51-8194	0.0%	16.7%
84-608-10	19.4%	18.8%
Q135	13.1%	19.4%
PELORUS	44.2%	20.5%
Q96	31.8%	24.9%
Q124	41.7%	30.4%
Q101	10.4%	34.4%
Q120	40.0%	37.5%
Q161	30.9%	44.0%
H78-7234	62.2%	52.3%
Q107	18.5%	52.5%
MQ79-141	57.0%	57.6%
Q150	90.8%	58.3%
90-110-9	41.7%	61.3%
MQ87-540	27.8%	63.6%
MQ87-155	38.2%	63.9%
ROC-1	61.7%	66.7%
KQ88-8075	75.4%	70.2%
Q137	78.1%	71.9%
84-608-3	34.7%	72.2%
88-402-2	70.8%	72.2%
Q113	40.3%	72.2%
87-105-10	43.3%	72.9%
84-608-6	75.0%	75.0%
BMQ89-77	100.0%	75.0%
Q162	85.4%	75.0%
Q138	100.0%	75.6%
BMQ89-14	78.1%	76.0%
BMQ89-15	78.3%	77.0%
89-605-1	33.0%	81.4%
KQ87-7339	100.0%	84.4%
NCO310	58.8%	86.3%
Q164	61.5%	86.9%
MQ63-693	40.1%	88.1%
Q121	71.4%	88.9%
Q154	96.4%	90.0%
Q115	64.0%	90.9%
TS68-830	60.7%	91.0%
Tellus	97.2%	91.7%
MQ84-524	97.2%	91.9%
84-255-4	100.0%	93.1%
MQ74-110	100.0%	93.8%
Q117	91.3%	93.8%
90-77-2	56.3%	94.7%
MQ87-1069	100.0%	97.2%
84-255-10	96.9%	100.0%
86-1151-3	94.4%	100.0%
87-628-3	49.6%	100.0%
88-271-6	97.5%	100.0%
89-338-1	100.0%	100.0%
89-503-6	86.1%	100.0%
BMQ89-338	56.9%	100.0%
EOS	100.0%	100.0%
KQ91-1003	92.3%	100.0%
Q122	100.0%	100.0%
Q127	100.0%	100.0%
Q157	100.0%	100.0%
Q158	100.0%	100.0%
Q159	100.0%	100.0%
Q91	96.4%	100.0%

The results above are the second inspection of the first ratoon cane. The harvest date of the plant cane was the 12th May 2000.

Some ratings may vary from the plant cane final inspection. For example MQ88-2047 had an 8% infection level in the final plant cane inspection and in the latest first ratoon inspection above has 0%. No whip development has occurred.

Variety H51-8194 has gone from 0% in the plant crop to 16.7% in the ratoon crop. This variety was severely affected by top rot in the plant crop.

IRRIGATION TRIAL Summary of results to date.

PLANT CROP Q99 (1998 – 1999)

	TREATMENTS			
	60mm evaporation	120mm evaporation	180mm evaporation	
Irrigations to canopy closure (5/5/98 – 18/9/98)	8	8	8	
Number Irrigations since canopy closure (18/9/98 – 3/8/00)	20	11	7	
Amount of water applied (Megalitres)	36	19.8	12.6	
Cane Yield (tonnes per hectare)	218.4	211.7	198.4	No significant difference
Pol (%) in cane	12.35	12.23	12.98	No significant difference
Sugar (tonnes per hectare)	26.97	25.89	25.75	No significant difference

FIRST RATOON Q99 (1999 – 2000)

	TREATMENTS		
	25-30 mm soil deficit	60- 65 mm soil deficit	95 – 105 mm soil deficit
Irrigations to canopy closure	7	7	7
Number Irrigations since canopy closure	16	6	2
Amount of water applied (Megalitres)	27.3	10.5	3.6

**Soil deficit is calculated assuming there is approximately 300 mm of water in the soil to a depth of 80 cm.

ORD SUGAR INDUSTRY
FIELD DAY NOTES
JULY 2001

IRRIGATION

Water use
Irrigation scheduling trials – current & future
New water use work
Irrigation guidelines (Ute guide)
Bed geometry and application efficiency work started.

NUTRITION

Nutrient removal and cane composition
Tissue testing – 2000 results and 2001 testing.
Cane nutrition – Possible visit by Bernard Schroeder late 2001

VARIETY & SMUT SCREENING UPDATE

Smut trial update – Smut trial 2 plant inspection results

OTHER

Weeds in cane
Weigh bin
BSES proposal
Bug trapping

Jim Engelke, Joe Sherrard, Gae Plunkett, Tim Triglone
Department of Agriculture
Sugar Research, Development & Extension
Kununurra WA

IRRIGATION

- → Water use – EnviroSCAN and Diviner work.
- → Irrigation scheduling trials FWI. (Current & Future trials) Need 3rd treatment for future trial.
- → New water use work – Need late cut, accessible, good stand of cane for annual water use study.
- → Irrigation guide and demonstration.
- → Bed geometry for water application efficiency work has started (no notes included)

Cane water use:

The graph of water on B27 has been constructed using the "EnviroSCAN", which records changes in soil moisture content at pre determined intervals (15 minutes in this case). The soil moisture changes that result in water being removed from the soil are added for each day and a daily water use in millimetres can be established.

Soil moisture can change as a result of;

1. Crop water use
2. Evaporation
3. Deep drainage

For measurements at Block 27, the impact of deep drainage has been minimal and is less well defined for blocks 45 and 76. Water use figures are presented in table 1.0.

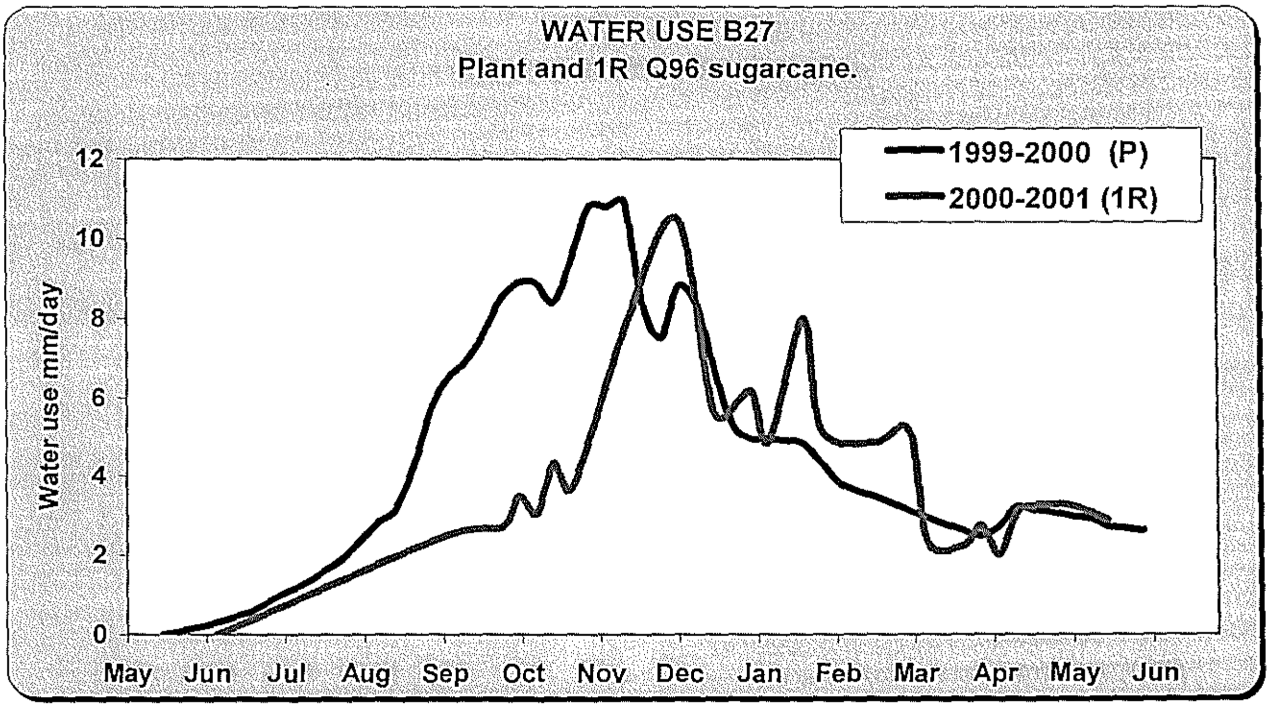


Figure 1: Water use, as determined by change in soil moisture content, for a plant and first ratoon sugarcane crop (Q96) on Block 27 – 40.

The next two graphs (Figures 2 & 3) of water use have been constructed using the "Diviner". Measurements of soil moisture are taken daily. Water use can be determined by summing the total of the changes in soil moisture. As a result of the single reading per day this method is not as sensitive as using the EnviroSCAN. Additionally the contribution of rainfall is more difficult to establish using the Diviner.

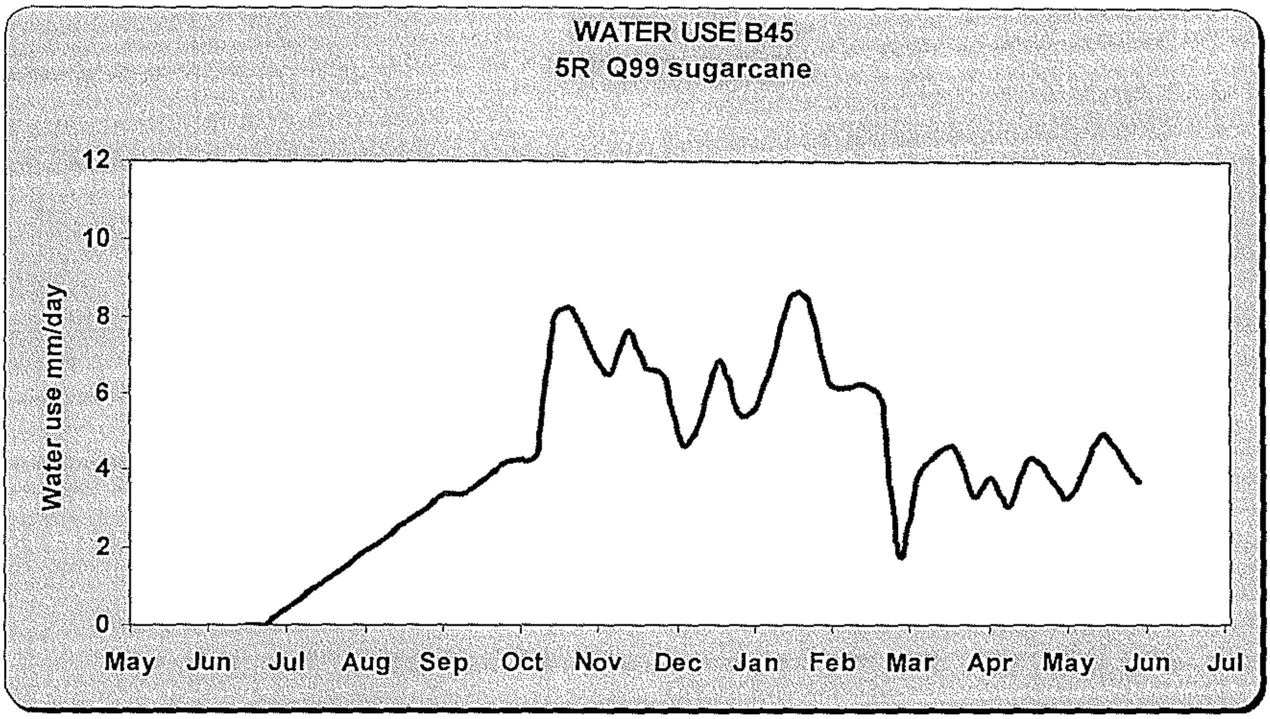


Figure 2: Water use, as determined by change in soil moisture content, of a fifth ratoon sugarcane crop, Block 45.

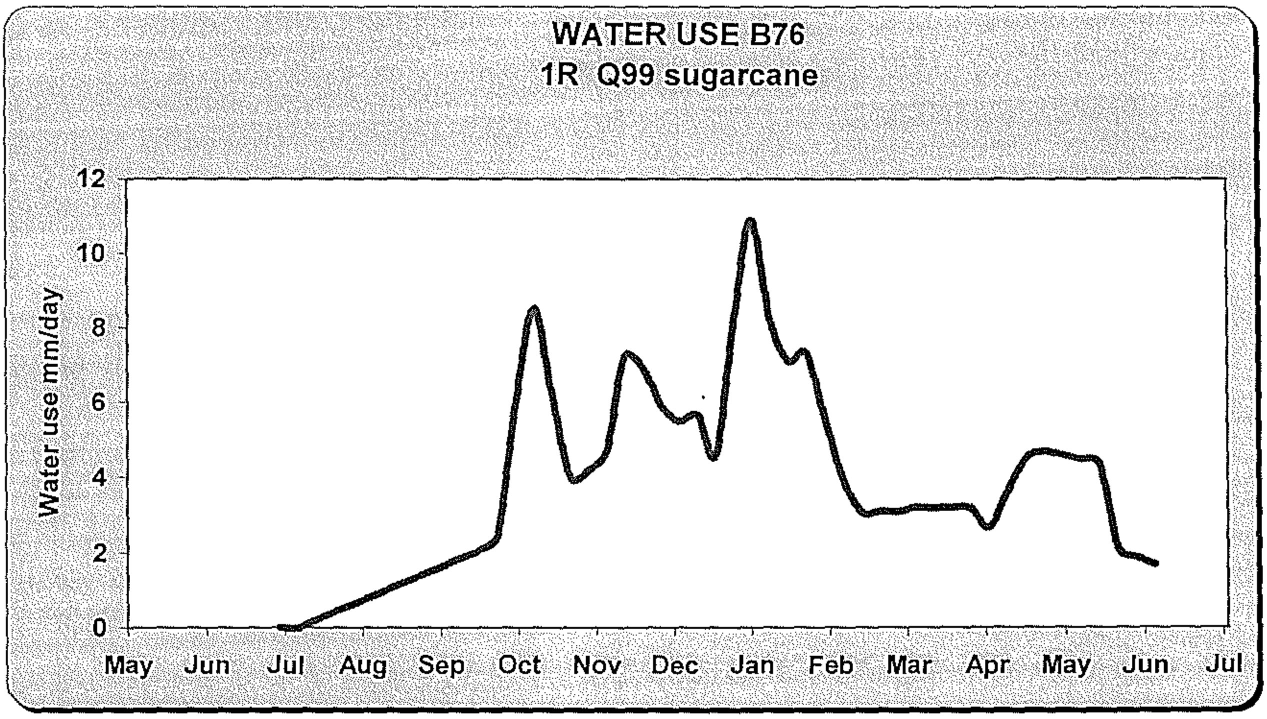


Figure 3: Water use, as determined by change in soil moisture content, of a first ratoon sugarcane crop, Block 76. NOT YET HARVESTED.

Table 1: Crop water use estimated using soil moisture monitoring techniques.

Block	Crop	Water use (ML/ha)	Yield (tonnes cane /ha)	Water use (tonne cane/ML)
B27	Plant 99/00	17.3	186	10.8
B27	1R 00/01	13.5	140	10.4
B45	5R 00/01	15.3	113	7.4
B76*	1R 00/01	13.8 to 29/6/01	N/A	N/A

* Block not harvested.

Irrigation scheduling trials - update

Current trial to be final harvest expected to be October 2001.

Future trial beginning July 2001.

1. Using APSIM (Irrigate when 50% of Plant Extractable Soil Water remains)
2. Using APSIM at ?? (drier treatment to be determined)
3. Grower established treatment.

NUTRITION

- → Nutrient removal and cane composition.
- → Tissue testing – 2000 results, and 2001 testing.
- → Tissue testing – Bernard Schroeder (BSES) visit possible towards end of 2001

Nutrient removal / usage

A number of crops were sampled in the 2000 harvest season for nutrient content and removal / usage. Whole stalks were removed from the paddock and separated into stalk, cabbage, green leaves and dead leaves. Only dead leaves still attached to the stalk were recovered for weight and nutrient analysis.

Variety	Q96	Q96	Q99	Q99	Q99	
Class	P	1R	4R	4R	3R	
Farm	Cummings	Cummings	Innes	Cummings	Oasis Bananas	
Harvest date	8/6/00	24/7/00	16/7/00	16/8/00	22/10/00	
Harvest yield	187	170	124	142	138	
Pol %	13.2	14.3	14.8	15.4	15.4	
NUTRIENT	KILOGRAMS PER TONNE WHOLE FRESH CANE					AVERAGE
Nitrogen	2.08	1.55	1.89	1.35	0.99	1.57
Phosphorus	0.21	0.19	0.30	0.25	0.19	0.23
Potassium	3.50	2.64	2.08	2.85	2.07	2.63
Sulphur	0.44	0.22	0.12	0.16	0.14	0.22
Calcium	0.32	0.36	0.53	0.52	0.54	0.46
Magnesium	0.25	0.25	0.47	0.37	0.45	0.36
	GRAMS PER TONNE WHOLE FRESH CANE					
Copper	0.7	0.7	1.0	0.8	0.9	0.8
Zinc	3.3	3.3	5.1	5.8	6.5	4.8
Manganese	6.2	8.4	28.9	19.6	10.9	14.8
Molybdenum	0.0	0.1	0.1	0.2	0.1	0.08
Iron	39.7	32.3	35.7	40.6	72.2	44.1
Boron	0.5	0.6	0.9	1.3	1.3	0.9
Sodium	47.2	49.5	138.9	89.8	93.9	83.7

Composition of sugarcane

Using data collected from the nutrient removal work it is possible to generate information of the composition of sugarcane by component (stalk, cabbage, green leaves, dead leaves). Presented in the table below are the averages for the five crops analysed for nutrient removal / usage.

	STALK	CABBAGE	GREEN LEAVES	DEAD LEAVES
WET	86.7%	6.7%	5.1%	1.5%
DRY	82.6%	6.8%	6.7%	3.9%

Tissue analysis

Several tissue samples were taken of crops late in 2000. These were analysed for nutrient content and compared to critical values established in Queensland and overseas. None of the samples taken displayed nutrient limitations using the critical values. Some of the samples taken are presented in the table below.

It is planned to take more samples this year.

NUTRIENT	CRITICAL NUTRIENT VALUES**	UNIT Dry Weight	P Q99	5R Q99	1R Q96	100kg/ha Potassium	No Potassium
Nitrogen	1.8	%	2.01	2.43	2.23	2.39	2.62
Phosphorus	0.19	%	0.27	0.19	0.24	0.23	0.24
Potassium	1.1	%	1.46	1.29	1.51	1.52	1.57
Sulphur	0.13	%	0.16	0.15	0.16	0.16	0.16
Calcium	0.18	%	0.29	0.25	0.36	0.37	0.38
Magnesium	0.08	%	0.23	0.18	0.24	0.18	0.18
Copper	2-3	mg/kg	5.6	4.7	6.1	5.8	6.1
Zinc	10-12	mg/kg	15.6	18.5	15.8	23.1	23.4
Manganese	15	mg/kg	53	48	51	79.7	86.7
Molybdenum	0.08	mg/kg	0.3	0.4	0.3	0.9	1.2
Iron	50	mg/kg	76	91	89	95	100
Boron	1-2	mg/kg	9.5	5.8	9.7	16.4	16.2

** Plant nutrient concentrations need to maintained above the 'critical nutrient values' to ensure no nutritional limitations. The critical levels in this table are based on information from other cane growing areas.

VARIETY & SMUT SCREENING UPDATE

Smut Trials

Smut Trial 1 – Planted September 1999: Completed plant and first ratoon rating

Smut Trial 2 – Planted July 2000: Completed plant rating

Smut Trial 3 – Planted May 2001:

SMUT TRIAL 2 - Mean Infection at final plant crop inspection (30/3/01), sorted by level of infection.

Variety	Mean Infection
89-247-5	0.0%
89-393-1	0.0%
89-393-3	0.0%
89-518-6	0.0%
89-680-3	0.0%
89-680-6	0.0%
90-83-5	0.0%
95H4004	0.0%
95H4021	0.0%
95H4024	0.0%
95H4039	0.0%
CP74-2005	0.0%
KQ88-8151	0.0%
MQ88-2022	0.0%
MQ88-2047	0.0%
ORPHEUS	0.0%
Q125	0.0%
Q130	0.0%
Q142	0.0%
Q155	0.0%
Q171	0.0%
z-Q95	0.0%
z-Q99	0.0%
95H4040	3.3%
90-77-5	8.3%
Q101	13.2%
95H4001	15.0%
95H4035	15.6%
Q107	22.0%
Q145	22.2%
95H4005	24.5%
95H4047	25.7%
95H4007	26.7%
Q135	26.7%
95H4029	27.0%
95H4048	27.6%
Q161	31.5%
z-Q96	36.8%
95H4022	38.0%
95H4010	45.6%
84-608-10	48.6%
95H4003	50.1%
95H4033	63.3%
95H4030	63.8%
95H4016	66.7%
95H4044	66.7%
95H4032	69.8%
95H4023	74.4%
95H4008	75.8%
95H4027	76.7%
67N3184	79.2%
KQ91-2616	83.8%
95H4018	88.9%
z-NCO310	95.2%
95H4006	100.0%
95H4012	100.0%
95H4017	100.0%
95H4020	100.0%
95H4037	100.0%
95H4046	100.0%
Q141	100.0%
Q165	100.0%
Q179	100.0%
z-Q117	100.0%

The results of smut trial 2 plant ratings confirm those of smut trial 1. The final rating of the ratoon crop will be carried out later in 2001 (Nov).

OTHER

- → Weed pressure in sugarcane
- → Weigh bin purchased and operational.
- → BSES proposal being pursued.
- → Bug trapping being carried out in ORIA sugarcane crops 2001.

Weeds – Residual control

In 2000 the weed pressures were noticed by a number of people to have increased in the sugarcane fields. Both broadleaf and grass weeds were observed to have increased generally across the ORIA.

Some options for residual control of broadleaf and grass weeds on early emergent cane include:

TREATMENT	RATE / ha	APPROX COST	COMMENTS
Atrazine + Ametryn (Gesapax Combi)	3L + 3L (6-8L)	~$60/ha	.
Atrazine + Diuron	2.2kg + 1.2kg	~$48/ha	
Atrazine + Flame	2.2kg + 400ml	~Flame price not available in ORIA	No information on performance in ORIA. Avoid on sandy soils.
Atrazine + Stomp	2.2kg + 3L	~$63/ha	
Atrazin + Trifluralin CR	2.2kg + 4.5L	~$68/ha	Limited information on performance in the ORIA.
Atrazine + Balance	1.0kg + 200g	~$64/ha	Not for use on plant cane.

***Check rates and prices and suitability with chemical sales organisation.*

ORD SUGAR INDUSTRY

FIELD DAY NOTES

OCTOBER 2001

IRRIGATION

- 9A New irrigation trial
- Irrigation guidelines (Ute guide)

VARIETY UPDATE

- Replicated Variety Trial 1 – 1 Ratoon results
- Replicated Variety Trial 2 – Plant results
- 2001 cane introductions

OTHER

- Solar radiation investigation

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Department of Agriculture
Sugar Research, Development & Extension
Kununurra WA

SUGAR CANE – IRRIGATION TRIAL 9A Frank Wise Research Institute

Map

9 rows - no treatment	Grower treatment	APSIM: Irrigate when 50% of PESW remaining	APSIM 10% yield reduction	APSIM: Irrigate at 50% of PESW remaining	APSIM 10% yield reduction	Grower treatment	APSIM 10% yield reduction	Grower treatment	APSIM: Irrigate at 50% of PESW remaining
	white	red	yellow	red	yellow	white	yellow	white	red
	2	1	3	1	3	2	3	2	1

RESEARCH STATION ROAD

HEAD DITCH

Crop Log

PLANT CROP

Planted	20 June 2000
Harvested	5 July 2001
Yield	149.8 tonnes per hectare

1 RATOON

	Irrigation Treatments		
	Grower	APSIM (50% PESW remaining)	APSIM (10% yield reduction)
Herbicide	6 July 2001– Gesapax combi		
1st irrigation	8 July 2001		
Fertilised	7 August 2001		
2nd irrigation	10 August 2001		
3rd irrigation (days since last irrigation)	31 Aug 2001 (21)	5 Oct 2001 (55)	~ 23 Oct 01 (73)
4th irrigation	18 Sept 2001 (18)		
5th irrigation	2 Oct 2001 (13)		
Future irrigation schedules	12 day intervals up to December	7 day intervals up to December	10-13 day intervals from 20 October to December

SUGAR CANE – VARIETY TRIAL RESULTS (Plant cane – 2000 planted trial)

Two variety trials were due for harvest in 2001. The plant cane was harvested in July 2001. The first ratoon crop will be harvested in September 2001. Listed in dot below is a summary of the relevant crop husbandry.

- Pre-fertilised: Depth 150mm.each side of bed centre.
- Fertiliser mix: DAP-90%, Zinc Sulphate (mono) -7%, Sulphur - 3% at 300kg/ha.
- Planted: 23rd and 24th May 2000
- Irrigated: On top of cane 25/5/00 Watered @120mm. Evap.
- Herbicide: Atradex 900 @ 4kg/ha
- Fertilised: Urea @ 300kg/ha. 23/8/00....ridge up.
- Irrigation: Watered @ 70mm.evap
- Harvested: 4th and 5th July 20001

The table below presents the plant cane harvest results from 2000 planted replicated variety trial, sorted by sugar yield per hectare. All canes included in this trial have been previously assessed for smut resistance/susceptibility. Both resistant (0-10%) and intermediate (10-20%) canes are included in the variety trials. For varying reasons several canes in excess of 20% smut infection have also been included in the trial. Current commercial varieties Q96, Q99 and Q101 continue to perform well. Mida (MQ88-2047) which is undergoing field evaluation in the ORIA also performed well.

Variety	CCS	Cane yield (t/ha)	Sugar yield (t/ha)	Smut rating (ST1- 1R)
Q96	13.4	173.7	23.3	24.9%
MIDA (MQ88-2047)	13.1	168.5	22.1	0%
Q101	12.0	182.2	21.8	34.4%
Q99	11.7	172.7	20.2	0%
MQ80-805	12.3	155.0	19.0	0%
Q135	11.0	170.2	18.8	19.4%
KQ88-8151	12.1	154.2	18.7	0%
Q142	10.2	181.8	18.6	3.1%
Q130	11.1	165.2	18.5	0%
84-608-10	10.7	172.9	18.4	18.8%
89-393-1	11.5	160.2	18.4	0%
Q155	11.8	156.5	18.4	0%
MQ88-2022	9.1	198.9	18.3	0%
ORPHEUS	11.7	149.4	17.4	9.4%
Q171	11.3	153.5	17.4	0%
Q124	10.8	158.5	17.1	30.4%
Q95	11.2	152.3	17.1	0%
KQ91-2616	9.8	171.3	16.8	83.8%
89-518-6	10.5	159.2	16.7	0%
90-77-5	11.8	139.8	16.6	15.7%
Q125	11.6	137.4	16.0	0%
89-393-3	11.7	134.6	15.7	0%
90-83-5	10.9	138.3	15.1	3.6%
89-680-6	9.1	162.0	14.7	0%
95H4035	9.9	132.0	13.0	15.6%
89-247-5	9.5	95.9	8.9	0%
Average	11.3	158.4	17.9	
LSD (P<0.05)	2.03	23	4.07	

SUGAR CANE – VARIETY TRIAL RESULTS (1 Ratoon – 1999 planted trial)

Harvested 18th September 2001

The first ratoon results of Replicated Variety Trial 1 (RVT1) are presented in the table below. This trial was planted before adequate smut screening data was available. As a result a number of susceptible canes were included in the trial. Varieties such as Q161 and MQ74-110 are too susceptible to smut to be considered for commercial use.

The trial has been ploughed out due to the high levels of smut infection present. All varieties considered resistant to smut have been included in further variety trials.

Variety.	CCS	Cane yield (t/ha)	Sugar yield (t/ha)	Fibre %	Smut %
Q161	14.1	178.7	25.1	13.6	70
PELORUS	14.2	162.7	23.1	13.0	28
Q96	14.6	154.9	22.6	15.5	35
MQ74-110	13.7	157.7	21.6	13.2	100
KQ91-31506	14.3	146.4	20.9	15.6	18
MQ88-2047 (MIDA)	15.2	136.8	20.7	13.3	0
Q99	13.7	144.9	19.8	13.8	2
KQ91-31405	11.6	166.8	19.4	15.8	6
MQ79-141	12.5	148.8	18.6	16.3	67
Q142	12.9	143.4	18.6	13.0	3
MQ87-155	10.4	178.1	18.5	14.3	77
89-503-10	12.2	152.1	18.5	13.9	6
Q138	12.8	142.1	18.2	13.2	92
BMQ89-15	12.0	149.9	17.9	13.0	95
BMQ89-77	12.8	139.8	17.8	16.1	100
Q127	12.0	145.5	17.5	13.7	100
BMQ89-14	11.6	149.6	17.4	14.3	80
KQ91-20301	11.1	153.3	17.0	16.6	95
ORPHEUS	13.1	126.8	16.6	14.3	11.6
Q155	11.6	139.8	16.2	14.1	0
Q124	12.8	124.6	15.9	13.4	39
89-680-3	11.2	141.8	15.9	16.6	0
KQ88-8075	13.4	118.1	15.9	12.9	75
Q125	11.6	123.6	14.3	14.1	0
89-518-6	11.7	121.4	14.2	13.5	0
Q122	12.8	105.8	13.6	16.2	100

SUGAR CANE – 2001 Introductions

Listed in the table below are the 96 canes introduced into the ORIA in 2001. Canes were accessed through CSIRO and the BSES. The column titled 'Source' identifies where the canes were obtained.

The canes listed below will be placed into a smut screening trial in 2002. Those canes that display suitable smut resistance will then be placed into a replicated variety trial in 2003 and assessed for CCS and fibre percent and cane yield.

It is anticipated that a similar or greater number of canes will be introduced in 2002 and 2003.

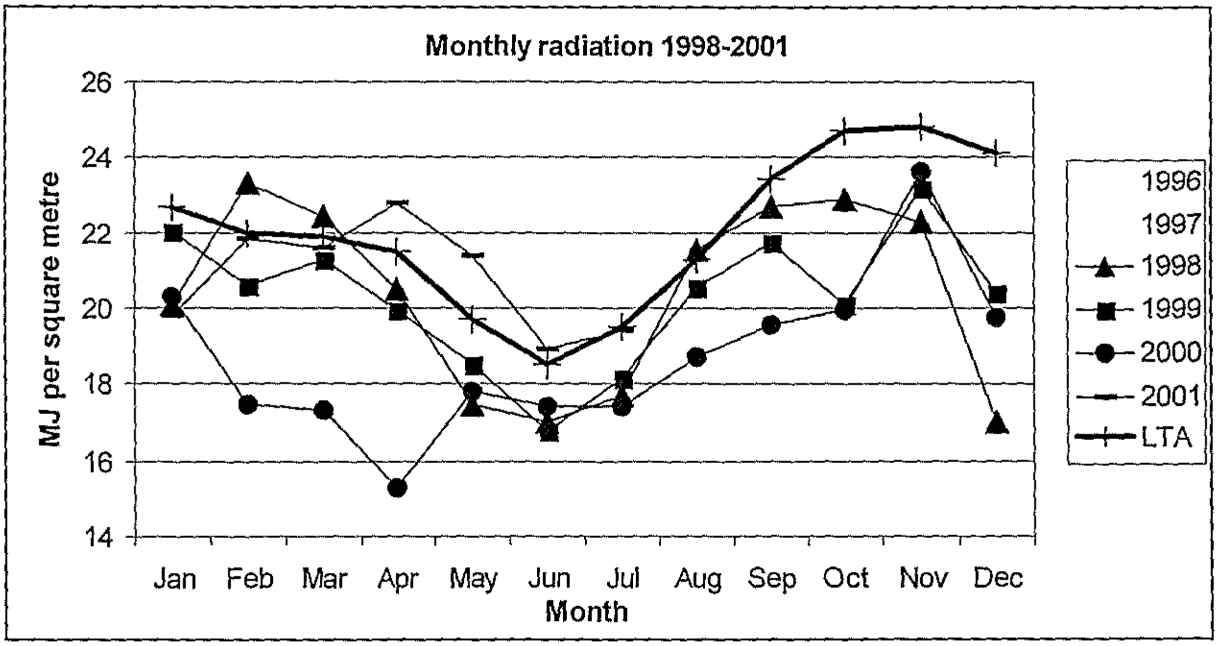
Variety	Origin	Source
68W1049	South Africa	CSIRO
78F1025	South Africa	CSIRO
86C451	QLD BSES	CSIRO
BJ7452	Jamaica	CSIRO
BT65152	Barbados	CSIRO
C1616-75	Cuba	CSIRO
CASSIUS	QLD CSR	CSIRO
C-GD-24	China	CSIRO
CL74-1217	USA Florida	CSIRO
CO8232	India	CSIRO
CP75-1322	USA Canal Point	CSIRO
EAK7076	East Africa	CSIRO
H60-3802	Hawaii	CSIRO
IAC52-150	Brazil	CSIRO
JA64-19	Cuba	CSIRO
LF68-10140	Fiji	CSIRO
MS70-611	China	CSIRO
N14	South Africa	CSIRO
N17	South Africa	CSIRO
N19	South Africa	CSIRO
N22	South Africa	CSIRO
PHIL66-07	Philippines	CSIRO
Q129	QLD BSES	CSIRO
Q182	QLD BSES	CSIRO
R80-542	Reunion	CSIRO
R81-970	Reunion	CSIRO
RB76-5418	Brazil	CSIRO
RB80-5004	Brazil	CSIRO
SP79-2313	Brazil	CSIRO
TC4	Malaysia	CSIRO
TC5	Malaysia	CSIRO
TC6	Malaysia	CSIRO
TS68-2599	Taiwan	CSIRO
TUC74-24	Argentina	CSIRO
VMC67-315	Philippines	CSIRO
CP81-1405	USA Canal Point	BSES
CP88-1409	USA Canal Point	BSES
CP88-1508	USA Canal Point	BSES
CP88-1540	USA Canal Point	BSES
CP88-1762	USA Canal Point	BSES
CP92-1213	USA Canal Point	BSES
CP92-1641	USA Canal Point	BSES
CP92-1666	USA Canal Point	BSES
H78-3567	Hawaii	BSES
H78-3606	Hawaii	BSES
H78-7750	Hawaii	BSES
H83-7206	Hawaii	BSES
H84-0778	Hawaii	BSES
H85-7362	Hawaii	BSES
H87-4094	Hawaii	BSES
H87-4319	Hawaii	BSES
HCP85-845	USA	BSES
HCP91-555	USA	BSES
LCP85-384	USA	BSES
LCP86-454	USA	BSES
M1176-77	Mauritius	BSES
M1551-80	Mauritius	BSES
M1658-78	Mauritius	BSES
M2350-79	Mauritius	BSES
M261-78	Mauritius	BSES
M52-78	Mauritius	BSES
N23	South Africa	BSES
N24	South Africa	BSES
N25	South Africa	BSES
N26	South Africa	BSES
N28	South Africa	BSES
N29	South Africa	BSES
N30	South Africa	BSES
N31	South Africa	BSES
R84-0075	Reunion	BSES
R84-0408	Reunion	BSES
R84-0472	Reunion	BSES
R85-0252	Reunion	BSES
R85-0348	Reunion	BSES
R85-0449	Reunion	BSES
R85-0579	Reunion	BSES
R85-0699	Reunion	BSES
R85-0991	Reunion	BSES
R85-1102	Reunion	BSES
R85-1157	Reunion	BSES
R85-1238	Reunion	BSES
R85-1334	Reunion	BSES
ROC13	Taiwan	BSES
ROC15	Taiwan	BSES
ROC16	Taiwan	BSES
SP77-5181	Brazil	BSES
SP79-2233	Brazil	BSES
SP80-1816	Brazil	BSES
SP80-1836	Brazil	BSES
SP80-1842	Brazil	BSES
SP80-185	Brazil	BSES
SP81-1763	Brazil	BSES
SP81-3250	Brazil	BSES
SP83-5073	Brazil	BSES
TCP87-3388	USA	BSES
TCP89-2377	USA	BSES

SUGAR CANE – Radiation 1998 - 2001

The graph below presents the average monthly radiation figures for the years 1998 through to July 2001.

Using the computer model APSIM and the solar radiation figures presented below, sugarcane cane growth was modelled. APSIM did not show that solar radiation was a limiting factor to sugarcane growth over the 2000/2001 season. It did suggest that solar radiation may have been limiting over the 1999/2000 growing season. However, we know that the yields in that season did not suffer as they have for the 2000/2001 season.

Solar radiation on its own does not provide a clear reason for the yield reduction experienced in the 2001 harvest season.



ORD SUGAR INDUSTRY
FIELD DAY NOTES
JULY 2002

9A IRRIGATION TRIAL

9A irrigation trial is an extension of the trials being conducted on 2B harvested over the period 1999-2001. The trials at 2B identified that sugarcane was not responding significantly in terms of yield and pol % to the irrigation scheduling imposed. These schedules were considered extreme.

The three trials on 2B experienced above average wet season conditions. We were keen to run a trial through a lower rainfall wet season. Also knowing the factors we had identified at 2B such as refill points, we designed 9A irrigation scheduling more closely with what might be considered a commercial practice. Additionally 9A is also of a size that could be considered commercial production.

9A Crop Log

Plant

- Planted June 2000
- Block treated under normal commercial procedures
- Plant crop harvested 5th July 2001,
    - yield 150 tonnes per hectare, 14.89% pol, 22.3 tonnes pol / ha

First ratoon

- Gesapax combi – 8 litres / ha
- Irrigated (entire paddock) - 8/7/02
- Fertilised - 317kg Urea, 243kg DAP (190kg N/ha, 49kg P/ha)
- Irrigated (entire paddock)
- Irrigation treatments imposed
    - 1. D50 – Remove 50% plant available water (assumed 200mm in 2 metres)
    - 2. Grower – Average of growers operations.
    - 3. S10 – Aimed at achieving in a 10% yield reduction.

Irrigation scheduling results

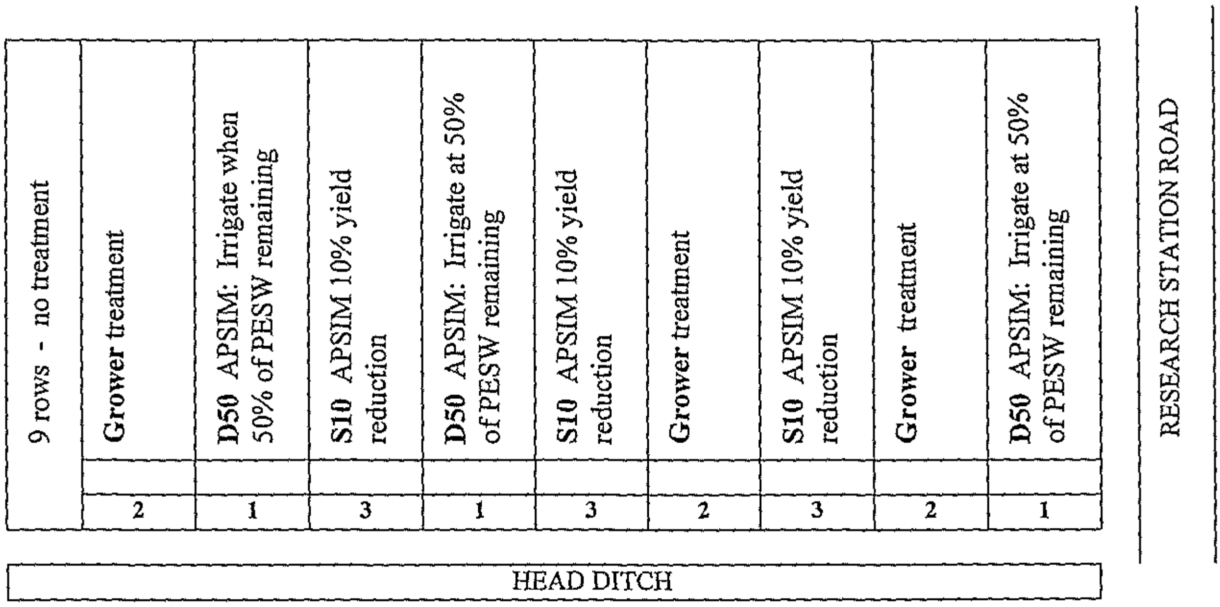
	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	No Irrigations	**Total Ml/ha
D50	1	1		3	2	2			1	2	1		13	21.2
Grower	1	2	1	3	1	2	1	1	2	2	2	1	19	27.9
S10	1	1		1	2	1				1	1		8	13.6

** Total Ml/ha is an approximation based on assuming 0.8 Ml/hr from the dethridge wheels, 0.2Ml/hr lost over channel stop, remainder is applied to the paddock. Total hours irrigation multiplied by 0.6 Ml/hr. No concerted attempt was made to improve irrigation efficiency during this trial.

Hand sampling yield and CCS results

Sample Date		D50	Grower	S10	SE
Pre wet – 3/12/01	Yield	79.6	73.2	68.3	3.3
Post wet – 9/4/02	Yield	114.1	102.5	100.1	8.0
Harvest – 25/6/02	Yield	131	127.1	128.5	9.9
Harvest – 25/6/02	CCS	12.7	13.6	11.9	0.7

Map



** Steel posts with flagging tape are in the centre of each treatment