STRATEGIES FOR MAXIMISING SUGARCANE YIELD WITH LIMITED WATER IN THE BUNDABERG DISTRICT

C.P. Baillie[1] and S.R. Raine[2]

[1] Agricultural Engineer, Bundaberg Sugar Ltd, Bundaberg
PO Box 500, Bundaberg Q 4670, ph (07) 4150 8500
[2] Associate Professor, Faculty of Engineering and Surveying, University of Southern Queensland, Toowoomba

ABSTRACT

Between 1995 and 2003 sugarcane farmers in Bundaberg had access to limited irrigation water. Over this time water allocations were effectively a quarter of the requirements for a fully irrigated crop. In response to this problem irrigation strategies were developed to assist farmers. Field investigations focused on the performance of water winch and furrow irrigation systems, which make up 91% of the irrigated area in the district. As most of these application systems have insufficient capacity to meet crop demands, opportunities to schedule irrigations were limited to start up after rain.

Improvements in irrigation system performance were found to provide the greatest potential to increase sugarcane yield under conditions of limited water. Investigations identified that irrigation performance could be significantly improved through relatively minor adjustment.

Timing of irrigation start up after rain influenced how much water could be applied to the field. Even with relatively low allocations delayed start up strategies could lead to a situation where water was left over at the end of the season.

INTRODUCTION

From the early stages of the Australian sugar industry the need for irrigation was recognised as a means to stabilise yields in various districts and provide a management strategy to minimise the effects of droughts. The need for irrigation was noted in Bundaberg as early as 1870 when small scale irrigation was carried out from shallow wells. In 1885, pumps were installed at Bingera on the Burnett River to irrigate cane land and supply water to Bingera Mill. By 1901 a small irrigation scheme was developed by James Gibson (Bingera Mill) to irrigate 237 hectares of cane land. Droughts during 1902 to 1904 were pivotal in confirming the need for irrigation (Kerr, 1983).

Formal research into the benefit of irrigation in the Bundaberg region can be traced back as far as 1931 when trials were conducted to determine the potential yield benefits of irrigation (Kingston, 2000). In the Bundaberg District, supplementary irrigation is estimated to provide an increase in yield of 22.6 tonnes of cane per hectare or 3.6 tonnes of sugar per hectare (Holden, 1998).

Today, approximately 60% of the annual Australian sugar cane crop is produced by either full or supplementary irrigation (Ham, 1994). In recent years, significantly lower rainfall and major expansion in cane has placed a strain on irrigation water resources (Shannon et al, 1996). As water supplies become depleted irrigation practices need to change from the traditional practice of full irrigation.

Irrigation Water Supply

Irrigation water supplies in the Bundaberg district include surface water from the Bundaberg Water Supply Scheme and ground water from the Bundaberg Sub artesian Area. Surface water provides the most significant proportion of the supply with 74% of nominal allocations.

The total annual nominal allocation for irrigation is approximately 250 000 ML with 185 000 ML supplied from the Burnett Water Supply Scheme (DNR&M, 2003) and 65 000 ML from ground water (Ridge, 2000).

The Bundaberg Water Supply Scheme was designed in 1970 as a supplementary irrigation scheme. Water from the scheme was initially allocated to growers on an area basis at 4.5 ML/ha of cane assigned land. Based on a typical crop rotation of 70% of the assigned cane area, the amount of water available for irrigation was effectively 6 ML/ha. The irrigated area within the Bundaberg Water Supply Scheme has increased from 40 070 ha in 1970 to 55 300 ha in 1994. Considering this expansion and reduced water supplies from 1995 to 2003, the amount of water currently available for irrigation is approximately 50% of the full water supply allocated to growers in 1970. In addition, growers have often had to make decisions based on much less water as the announced allocation at the start of each season has ranged from 15 to 30% which is effectively 0.5 to 1.0 ML/ha of irrigation water.

Crop Water Requirements

The crop response to irrigation is both seasonally and spatially variable due to climatic differences from year to year and between districts within the Australian sugar industry. In Bundaberg, the annual crop water requirement of sugar cane is 1360 mm with 580 mm normally supplied by effective rainfall and 780 mm (7.8 ML/ha) required by irrigation (Holden, 1998).

Benchmark figures suggest that for a fully irrigated crop, 100 mm of irrigation on average would normally produce an additional 10 tonnes of cane per hectare (Tilley and Chapman, 1999). However, the response to irrigation is greater at lower allocations and diminishes as the amount of water applied to the crop is increased.

Project Aims

Historically, sugarcane farmers in Bundaberg have had limited access to irrigation. The district has the potential of growing 3.8 million tonnes of sugarcane. However, a series of dry seasons saw this reduce to 2.1 million tonnes in 2002. Compounding the effects of both dry seasons and limited water supplies has been a 30% reduction in the sugar price over this period.

A change from the traditional practice of full irrigation is required as water supplies become depleted. As there were no clear guidelines on how growers could respond to diminishing water supplies, this research investigated opportunities to fine tune irrigation practices and the performance of irrigation systems (ie. low cost solutions) that would assist growers to maximise sugarcane yield. This paper summarises the research undertaken and provides and overview of the strategies to maximise sugar cane yield with limited water in the Bundaberg District. Complete details of this work are presented in a research dissertation (Baillie, 2004).

METHODOLOGY

A multidisciplinary approach, incorporating engineering and agronomic aspects was employed to develop irrigation strategies which focussed on finetuning current practices as opposed to introducing new irrigation infrastructure or management systems. This broad approach was adopted to take advantage of all aspects of irrigation on farm. A variety of techniques were used including a grower survey, on-farm monitoring, targeted irrigation testing and analysis, and crop modelling.

Grower Survey

A grower survey was developed to benchmark and evaluate irrigation practices so that opportunities to develop irrigation strategies for limited water could be identified (Stehlik and Mummery, 2000). Questions relating to general farming practice, irrigation management, the operation of irrigation systems and irrigation scheduling were included in the survey questionnaire. The grower survey included 91 growers across the district that was using a range of irrigation application systems.

Over 115 questions were developed and included information on general irrigation management, the operation of irrigation systems and irrigation scheduling. Survey participants were randomly selected from a stratified sample based on location (mill area) and irrigation type. Individual surveys were conducted insitu (ie on the grower's property at a time and date that suited them).

Within the survey questionnaire the irrigation systems section included questions on the irrigation water supply and the application systems in use. The irrigation type section included specific questions relating to how irrigation systems were being operated. The irrigation scheduling section obtained information on the adoption of irrigation scheduling tools as well as the grower's understanding of soil water holding characteristics and crop water use.

On-farm Monitoring

Six field sites were monitored over two irrigation seasons to obtain an understanding of how the crop responded during the season to the management of limited water and the effects of irrigation system performance. Field sites were spatially distributed across the district and included different soil types, cultural practices and irrigation systems. Crop growth measurements were recorded on a daily basis and conducted in conjunction with soil moisture measurements to demonstrate the relationship between crop growth rates and soil moisture. This in turn demonstrated crop responses to management practices and irrigation system performance.

Crop growth measurements were determined from the average growth of 10 stalks measured to the top visible dewlap of the plant (Figure 1). Soil moisture was monitored down to 1 metre at each site using Enviroscans (Sentek Pty Ltd). The Enviroscan loggers were programmed to record soil moisture every 30 minutes and were configured with 1 metre probes and 4 sensors per probe. The sensors were located at 10 cm, 30 cm, 60 cm and 100 cm below the soil surface.

Figure 1 Measuring height to the top visible dewlap

Irrigation Testing and Analysis

Travelling Guns
The operation of travelling gun irrigators (Figure 2) was examined to identify how the machine could be fine tuned to maximise yield. The performance of these machines and the impacts of various settings were evaluated. These trials examined the uniformity of the system, measured by Christiansen's Uniformity Coefficient (CU) as a key indicator of performance.

Trials were conducted to measure the uniformity of travelling gun irrigators over a range of conditions. The trial work identified how changes to the settings on these machines could improve overall performance. Testing was conducted on a machine with the most common type of gun used in the Bundaberg District, a Nelson P200 gun with a 21^{o} trajectory angle. The travel speed of the cart was set at 20 metres/hour (approximately 1 chain per hour).

The uniformity of the sprinkler pattern was measured using catch cans arranged in transects either side of the winch track, known as a standing leg test and was presented by Gordon (2000). Other measurements recorded during the trials included hydraulic pressure at the gun, flow rate and wind speed and direction.

Simple changes to machine settings were evaluated to determine their impact on performance over a range of conditions. These settings included nozzle size and type, operating pressure and the gun arc angle.

Furrow Irrigation
The performance of furrow irrigation systems (Figure 3) was examined under commercial conditions to identify management practices which could be used to improve irrigation performance locally. These trials examined the Application Efficiency (AE) and Distribution Uniformity (DU) of the irrigation event as key indicators of performance. Field trials at seven sites investigated opportunities to improve AE and DU using the surface irrigation model SIRMOD II (Walker, 1999). SIRMOD II was used to measure current irrigation performance and optimise operational settings including furrow flow rate and cut-off times.

A range of field measurements were undertaken at each of the sites to calculate field infiltration characteristics used by SIRMOD II. Field measurements included furrow flow rate, irrigation advance, irrigation duration, length and slope of the field, furrow geometry and row width. Infiltration parameters were determined by the two point technique outlined by Elliot and Walker (1982).

Figure 2 Travelling Gun Irrigator

Figure 3 Furrow Irrigation (using layflat)

Crop Modelling

The crop simulation model APSIM Sugar, described by Keating et al. (1999), was used to evaluate the impact of different irrigation strategies for starting after rainfall. The APSIM model is a biophysical model and has been validated for a wide range of conditions in Australia and overseas (Keating et al., 1999). Crop simulation modelling was conducted over a 10 year period and used to test observations and strategies developed at monitoring for seasonal variation. Daily climate data for Bundaberg was obtained from the Bureau of Meteorology's 'SILO' database. These records included daily rainfall, radiation and maximum and minimum temperature.

The model was subject to the similar constraints of a water winch system in terms of capacity. It was identified that most irrigation systems have insufficient capacity to meet crop demands; opportunities to schedule irrigations were limited to start up after rain. Irrigation strategies therefore modelled the impact of starting earlier or later after rainfall on a light soil (PAWC of 88 mm) and a heavy soil (PAWC of 176 mm).

RESULTS & DISCUSSION

Travelling Irrigator Performance

The irrigation performance measured by Christiansen's Uniformity Coefficient (CU) ranged from 48% to 84% (with a mean of 73%). Overall the results were poor given a CU of 84 to 86% is traditionally considered acceptable (Smith et al., 2002). Opportunities were identified to improve the performance of water winches under commercial conditions. Wind speed and direction had the most significant influence on irrigation performance. Irrigation uniformity reduced as wind speed increased, particularly when the wind direction was parallel to the row.

Operational settings and system changes were identified to reduce the effects of wind and maximise the performance of the machine in less than ideal operating conditions. In particular nozzle type had a significant influence on the performance of the machine under these conditions. There are two types of nozzles available for travelling irrigators. Taper nozzles provide the greatest stream integrity and maximum throw distance in windy conditions while ring nozzles provide better stream break up which is softer on the crop.

Results suggested that water winches could be operated effectively up to a maximum wind speed of 15 km/h providing taper nozzles were used when the wind direction was parallel to the row. At wind speeds approaching 15 km/h and parallel to the row direction, taper nozzles were found to improve the uniformity of the machine by maintaining overlap (ie. the throw from the gun). At wind speeds between 10 to 15 km/h and parallel to the row a taper nozzle was found to improve CU by 16% when compared to a ring nozzle operating in near identical conditions. The difference between nozzle performance wasn't significant when the wind direction was across the row.

Growers were generally aware of the effects of wind speed and direction on the performance of travelling guns as indicated through the grower survey. Growers were asked to identify the maximum wind speeds and wind direction they would operate their systems. At wind speeds greater than 15 km/h, only 3% of growers irrigated when the wind was parallel to the row compared to 10% when the wind was across the row. At wind speeds between 10 and 15 km/h, 7% of growers irrigated when the wind was parallel to the row compared to 19% when the wind direction was across the row.

When the wind direction was across the row and wind speeds were greater than 10 km/h, 16% of growers used ring nozzles as opposed to 12% of growers using taper nozzles. Similarly 9% of growers used ring nozzles when the wind was parallel to the row compared to 1% of growers using taper nozzles. Overall the use of ring nozzles was much more common than taper nozzles. These results suggest a limited awareness of the benefits of using taper nozzles at higher wind speeds. The common use of ring nozzles at higher wind speeds suggest that the performance of the irrigator could be improved just by simply changing the nozzle.

From field monitoring of crop growth rates a relationship was developed which determined the impacts of yield as a result on non uniformity of irrigation systems (Baillie, 2004). Previous testing was re assessed and a linear relationship was fitted between Christiansen's Uniformity Coefficient and yield reduction. An 8% reduction in yield was determined for every 10% reduction in CU. When comparing the yield difference between tests where CU was increased by 16% due to the use of a taper nozzle a potential yield increase of 15% was determined.

Furrow Irrigation Performance

Irrigation performance varied significantly across the field sites with Application Efficiency (AE) ranging from 45 to 99% (mean of 79%) and Distribution Uniformity (DU) from 71 to 93% (mean of 82%). Substantial opportunities to improve irrigation performance were identified. In most situations the operation of furrow irrigation systems could be manipulated to achieve application efficiencies greater than 90% and distribution uniformities greater than 84%.

Furrow flow rate controls the amount of water applied to the field. Significant increases in irrigation performance of furrow systems can be achieved by altering furrow flow rate. The AE at one site was improved from 45% to 90% by changing the cup size to increase furrow flow rate. Furrow flow rates should be adjusted for specific soil and field conditions. Flow rates of approximately 1 L/s were consistently used across all of the field sites that were monitored. However, simulation modelling and field evaluations demonstrated that flow rates should be increased to 3 to 4 L/s on soils with high infiltration rates. Despite this, only 5% of growers surveyed knew the furrow flow rate of their system.

The duration of the irrigation or the cut-off time is also an important factor in maximising irrigation performance. In general, irrigation cut-off times were controlled so that the irrigation was turned off as water just reached the end of the field. At higher flow rates (3 to 4 L/s), the irrigation was turned off earlier as drainage was sufficient for the water to reach the end of the field. Results from the grower survey suggest a very good understanding of this concept. From the survey 83% of growers either turned the water off at the end of the field or before. Only 17% of growers soaked the end of the field and of these, 90% had tail water return or banked the end of the field.

In most cases, banking the end of the furrow reduced runoff by effectively damming the end of the field. This was found to improve the application efficiency, by reducing runoff, and the distribution uniformity, by improving infiltration at the end of the field. The exception was in situations where ponding occurred at the end of the field. Banking furrow ends also allowed the irrigation to be shut off earlier as surface water from the top of the field drained to the bottom of the field. The grower survey indicated 55% of growers banked ends. A significant proportion (81%) of growers reduced runoff by either banking the end of the field and/or tail water recycling.

Over the range of performances measured in the field, yield reduction due to non-uniformity of furrow irrigation systems wasn't as significant as for water winches. Maximum yield loss due to non-uniformity of furrow irrigation systems was approximately 7% compared to 35% for water winches. Similarly a linear relationship was derived between Distribution Uniformity and yield reduction for the furrow trials. A yield reduction of 1.3% was identified for every 10% reduction in DU. Increases in AE can be related to a nett increase in water applied to the crop and the resulting increase in yield was determined using a crop production function generated by APSIM. Where AE was increased from 45 to 90% by increasing furrow flow rate a potential increase in yield of 13 tonnes of cane per hectare could be achieved (assuming 2 ML/ha available irrigation).

Crop Response to Irrigation Timing

The grower survey identified that the capacity of irrigation systems in the Bundaberg District (specifically water winches) was insufficient to match fully irrigated crop water requirements. Under current operating practices, the majority of growers were unlikely to be over irrigating. From the data, 65% of winch and 63% of furrow systems applied equivalent to supplementary irrigation requirements of 5 mm/day or less. Only 12% of winch irrigators and 15% of furrow irrigators had application rates higher than 7 mm/day which is the peak transpiration of the crop.

Observations at field sites were consistent with the survey data as soil moisture at field sites were found to progressively decline during the season. These systems were operating at an irrigation deficit whereby the irrigation schedule was determined by the rotation period of the irrigation system. In effect these systems were self-scheduling. Therefore, a critical aspect of managing these systems was when to start irrigating after rainfall.

Soil moisture data recorded at field sites indicated that irrigation practices could be improved and cane yield increased by starting irrigation earlier after rainfall. Crop simulation modelling evaluated three irrigation start up scenarios (ie early, middle and late) which simulated a 14 day irrigation rotation being completed, midway through or just starting relative to a soil moisture deficit of 0.75 PAWC.

Modelling results indicated that the optimum irrigation strategy was only slight and that it varied between seasons, soil types and available water allocation. The slight increase in yield of the optimum irrigation strategy suggested that irrigation timing after rainfall was reasonably flexible. The insensitivity of irrigation start-up was believed to be due to the small amount of allocation being modelled (ie. 2 & 3 ML/ha) relative to the total crop water demand. The calculated effective rainfall for each of the irrigation strategies was almost identical which supported this view.

Some crop yield and water utilisation patterns emerged from the modelling. For example, starting irrigation early after rainfall provided greater opportunity to use all of the water supplies throughout the season. The greatest difference in yield occurred between irrigation treatments when water was left over at the end of the season (9.2 tonnes of cane per hectare). Where the start of irrigation after rainfall was late, the water allocation wasn't fully utilised in 30 % of the years modelled.

The early strategy was the highest yielding strategy for the light soil type where 3 ML/ha was available. The late strategy was the highest yield strategy for the heavy soil type where 3 ML/ha was available. It was also the highest yielding strategy for both soils where only 2 ML/ha was available. Modelling suggested that the most important aspect for irrigation scheduling with limited water was to use all of the available water supplies.

CONCLUSION

Simple changes to improve the performance of the irrigation application system showed greater potential to increase yield than irrigation timing. For water winches, every 10% reduction in CU resulted in a potential reduction in sugarcane yield of 8%. Simple changes to improve irrigation uniformity for winch systems, such as changing nozzle types, were found to increase sugarcane yield by 16%. Similarly, changing the furrow flow rate for furrow irrigations systems was shown to double the nett amount of water applied to the crop (ie. increase AE from 45% to 90%) under some circumstances. This resulted in a modelled yield increase of 13 tonnes of cane per hectare at an allocation of 2 ML/ha.

With only a limited amount of water available for irrigation ie 2 – 3 ML/Ha and irrigation systems that have limited capacity, opportunity for irrigation scheduling was limited to start up after rainfall. The timing of irrigations was not critical except if practices are too conservative and water is left over at the end of the season. Even with relatively low allocations late start up strategies resulted in a situation where water was left over at the end of the season.

Irrigation strategies with limited water should be focused towards maximising irrigation system performance. This requires relatively minor adjustment to the operation of these systems such as changing nozzle type (travelling irrigators) / cup size to adjust furrow flow rate (furrow systems).

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PRESENTING AUTHOR BIOGRAPHY

Craig Baillie is an Agricultural Engineer who has worked in the sugar industry for 10 years providing technical assistance to Bundaberg Sugar’s farming operations. Amongst a number of duties with Bundaberg Sugar, Craig has worked in irrigation research (CRC for Sustainable Sugar Production) and was seconded to the Bureau of Sugar Experiment Stations (BSES) as project and extension officer for the Rural Water Use Efficiency Initiative (RWUEI), Sugar. In 2005 Craig completed his Master of Engineering. His thesis titled “Strategies for Maximising Sugarcane Yield with Limited Water in the Bundaberg District” aimed to assist sugarcane farmers at a time when the Bundaberg district was suffering significant water shortages.