ENHANCING IRRIGATION MANAGEMENT PLANNING WITH ENVIROSCAN AND WATERSENSE

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ABSTRACT

Reliance on supplementary irrigation in the southern zone of the Queensland sugar industry has increased over the past decade mainly because of increased variability in rainfall. This has highlighted a need for precise planning in application of limited water supplies to sustain crop productivity and enterprise profitability. Historically, irrigation scheduling in sugarcane was planned on the basis of crop water deficits estimated from long-term average Class A Pan evaporation and pan factors for various crop growth stages. More sophisticated technology has become necessary to help plan irrigation programs that deliver the right amount of water to the crop at the right time and insure that downstream impacts are minimised. In recent years, capacitance soil monitoring systems have been highly effective in providing growers and advisors with an indication of the soil water status of a number of representative sites. However, most sugarcane enterprises include multiple paddocks and a complex array of crops in various stages of growth resulting from two distinct planting seasons (autumn and spring) and ratoon crops that regenerate after harvesting any time from July to December. Consequently, daily crop water demand varies considerably from paddock to paddock. The Class A pan approach was mainly used only as a general guide and often applied at the whole of enterprise scale. The ability to calculate irrigation schedules for individual paddocks was mostly limited to those with capacitance monitoring systems. The development of a web-based irrigation optimising technique WaterSense by CSIRO in conjunction with industry stakeholders has provided a means to constantly evaluate daily crop water requirement for individual paddocks, making it possible for Australian sugarcane growers to calculate “real time” irrigation schedules. This paper discusses integration of the WaterSense predictive scheduling technique into farm irrigation management programs. A Sugar Research and Development Corporation project delivering the WaterSense web-based irrigation management tool to growers in five Queensland irrigated sugarcane districts commenced in 2006. During its first operational phase, it compared soil moisture capacitance data with WaterSense recommendations and resulted in good correlation between monitored field soil moisture and the recommendations determined by WaterSense. This has strengthened confidence in the real-time facility of WaterSense and illustrated the potential of this versatile tool to deliver both effective irrigation scheduling and enhance skills in water management planning.

INTRODUCTION

The southern Queensland sugar industry has relied on supplementary irrigation for over 100 years. After dry years in the late 1800’s and poor rainfall in 1902 irrigation from wells and streams commenced in the Bundaberg district. The value of irrigation was evident but the skills and knowledge needed to utilise the resource to it best advantage were scarcely understood. Today’s sugarcane irrigators have greater knowledge of climate, soil and crop water use relationships; and a greater understanding of moisture required for the various phases of crop development.

Over the past decade rainfall has been inconsistent and Bundaberg sugarcane growers have faced similar soil moisture deficits to the pioneers. Successful implementation of irrigation best practice has often been dependent on the growers' capacity to estimate daily fluctuations in the soil water balance. Capacitance monitoring systems such as EnviroScan (Sentek Pty Ltd, Adelaide, Australia) have made it possible to monitor the soil water balance in real time for a limited number of fields. The recent development of the CSIRO's WaterSense web-based irrigation management tool (Inman-Bamber et al., 2005, 2006; Webb et al., 2006) will allow irrigators to calculate the daily soil water balance in multiple fields simultaneously. This paper reviews the approaches to irrigation management that highlight the practical and operational issues that prompted the development of WaterSense. Outcomes from EnviroScan field monitoring sites are compared with WaterSense deficits to assess the capabilities of the web-based system in the paddock environment and to identify gaps in skill required to effectively utilise the tool.

APPROACHES TO IRRIGATION MANAGEMENT

Early published information (Kerr, 1939) indicated that a young cane crop required infrequent light irrigation and a well-advanced crop would respond to heavy irrigations at more frequent intervals. Allowance for rain was considered necessary but as a general rule, interruption to irrigation during the summer season was not recommended until 50mm of rain had been recorded. This advice first highlighted the different moisture demands of crops of varying growth stages and demonstrated the need for a scheduling method, particularly in the summer season when integrating rain and irrigation for the best productivity outcome was most difficult.

During irrigation trials on krasnozem soil at Bundaberg, mean root zone moisture tension of 100 kPa was found to correspond with 250 kPa in the surface 0.3m (Kingston and Ham, 1975). Previous research had shown a growth rate decline for cane in Hawaii when tension at 0.3 m approached 200 kPa (Robinson, 1963). Stalk elongation rate in the Bundaberg trial was found to decrease very rapidly with increasing soil moisture until a mean root zone tension of 100 kPa was reached, this decline in growth rate slowed with higher moisture tension (Kingston and Ham, 1975). Initially, a pan factor of 1.0 was recommended for maximising cane yield, however research in Hawaii (Robinson et al., 1963) showed sucrose yield was optimised with a management ratio of 0.85 which was similar to irrigating when tension (matric potential) at 0.3 m is about 200 kPa.

Irrigation scheduling based on "Class A pan" crop factor relationships was encouraged from the 1970's.The use of the pan factor of 0.85 for a fully canopied crop became an accepted method of determining potential evapotranspiration (ET_P = pan factor x Class A pan evaporation), however the influence of soil water content, plant and meteorological factors on the relationship between potential, and actual crop ET (ET_C) necessitates that a high level of record keeping and calculated adjustment is required to determine daily crop ET_C.

Confidence in stalk elongation as a tool to calibrate irrigation scheduling increased and a co-ordinated extension program called "WATERCHECK" promoted irrigation scheduling using stalk elongation in relation to evaporation from a 100 L drum (mini pan) placed near the paddock concerned (Shannon et al., 1996). Scheduling irrigation with the mini pan enabled individual growers to monitor fields with different soil types simultaneously. Growth rate measurement (stalk elongation) relative to mini pan deficit was used to calibrate the irrigation schedule to soil water holding characteristics. This method showed promise but like "Class A pan" x crop factor calculations required daily effort in collection and correlation of data.

Commitment to irrigation scheduling is often linked to individual property management aims, productivity, cost and availability of water supplies etc. To overcome the reticence of irrigators to collect and record daily information, estimates of potential daily crop water use (ET_P) were developed by Mc Dougall and Hussey (1997), based on long term monthly average evaporation data and estimates of factors for canopy development (Table 1).

Table 1. Estimates of potential daily crop water use (ET_P) in mm/day

Crop Class	J	A	S	O	N	D	J	F	M	A	M	J
Autumn Plant	2.2	2.9	4.6	5.8	6.7	7.3	6.1	4.9	3.9	2.6	1.9	1.6
Early harvest ratoon	-	0.3	1.4	3.4	4.6	5.8	5.8	5.5	5.0	3.4	2.6	2.1
Late harvest ratoon	1.7	2.0	2.9	-	0.7	2.2	3.4	4.3	4.4	3.4	2.6	2.1

Irrigators were now able to develop seasonal farm irrigation plans based on the potential demand of crops of varying age however, the fickle nature of daily weather meant that effective real time scheduling still required calculation of a daily water balance based on evaporation, rainfall and applied irrigation. Introduction of capacitance monitoring systems provided an opportunity to overcome the issues of real time management. However, as most sugarcane farms have multiple paddocks that are planted or harvested at various times of the year, extrapolating soil moisture data from one paddock to the next required consideration of the particular stage of canopy development in each paddock. Use of capacitance monitoring across all farm paddocks in most instances is not feasible due to capital cost, management and/or installation issues.

A system with the flexibility to analyse, correlate and record real time meteorological and management influences at multiple paddock level was needed. Participatory research involving SRDC, CSIRO, Bundaberg Sugar Services and BSES Limited and several cane growers in the Bundaberg – Isis and Ord River districts lead to the development of the WaterSense web based scheduling tool (Inman-Bamber et al., 2005, 2006; Webb et al., 2006).

WaterSense is a sugarcane irrigation optimising technique for determining the best time to irrigate sugarcane based on crop age and available water supplies. Irrigators are able to calculate indicative irrigation schedules for individual paddocks based on real time (daily) information. The Penman-Monteith equation, as outlined in the Food and Agriculture Organisation (FAO) of the United Nations, Irrigation and Drainage paper 56 (Allen *et al*., 1998), is used to determine reference evapotranspiration (ET_0) from climatic parameters supplied by a CSIRO automatic weather station (AWS) network or by the Bureau of Meteorology's SILO database accessed through Queensland Depart of Natural Resources and Water (http://www.nrw.qld.gov.au/silo/ppd/index.html). WaterSense uses concepts from the APSIM modelling environment (Keating et al, 1999) to simulate canopy development and soil moisture content. Factors for soil and crop ET as well as crop stress are then derived (Inman-Bamber *et.al*., 2008).

WEB-BASED IRRIGATION SCHEDULING

A project involving the afore-mentioned parties and funded by the Sugar Research and Development Corporation (SRDC), commenced in 2006 to facilitate grower uptake of the irrigation planning and scheduling tool (WaterSense) to enhance irrigation management, assist with maximizing economic outcomes and reduce environmental impact from irrigation..

WaterSense is operated as a web page on a centrally located server that stores the data base for participating growers. No software is located on the growers' personal computer system which reduces the risk of corruption or data loss. Irrigators are able to input and edit details (Figure 1) to reflect the individual circumstances of each paddock or farm. The program can be run on as many individual blocks as desired. Inclusion of representative blocks that differentiate soil types, crop cycle stages and age is recommended.

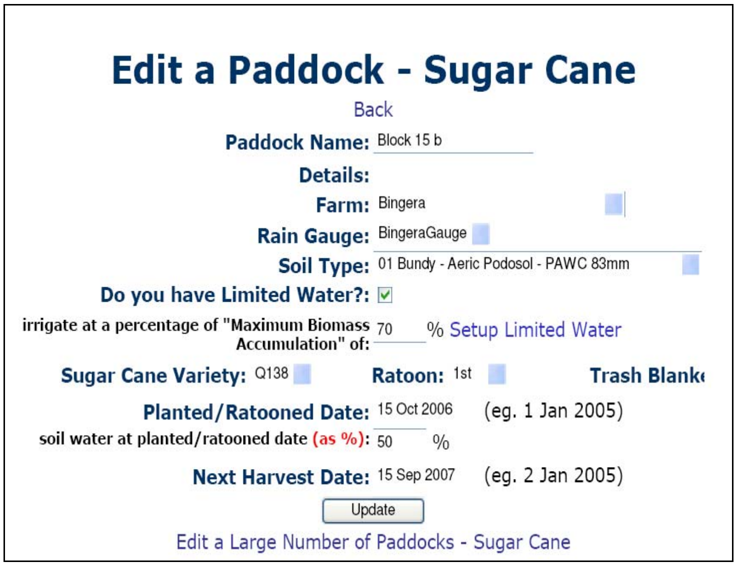
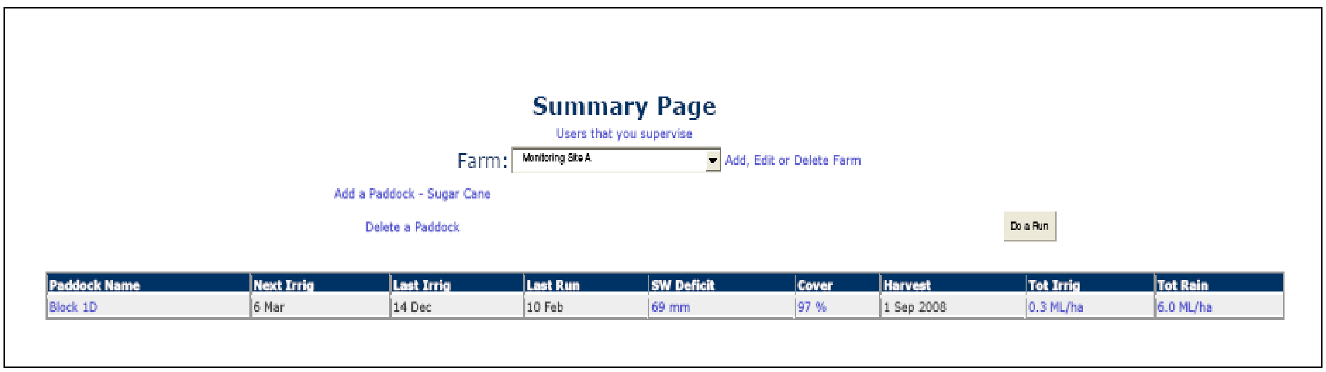


Fig 1 WaterSense data input page

WaterSense provides a summarised output (Figure 2) showing updated rain and irrigation, crop cover estimate, calculated soil water deficit and projected irrigation date.



Paddock Name	Next Irrig	Last Irrig	Last Run	SW Deficit	Cover	Harvest	Tot Irrig	Tot Rain
Block 1D	6 Mar	14 Dec	10 Feb	69 mm	97 %	1 Sep 2008	0.3 ML/ha	6.0 ML/ha

Fig 2 WaterSense summary page

Graphical information produced by “WaterSense” in Figure 3 shows the capability of the program to correlate factors contributing to the daily soil water balance.

- Blue line below zero represents soil water deficit
- Grey vertical bars above zero indicate the date and amount of rain recorded
- Dark blue vertical bars above zero indicate the date and amount of irrigation applied
- The red (dotted) line above zero represents biomass accumulation potential (crop growth rate %)
- “Irrigate when you go below this line” indicates crop growth rate has declined below the selected percent potential biomass accumulation
- X axis represents daily date, month and year; and
- Y axis has several interpretations:

  Below zero, shows accumulated moisture deficit (mm);
  Above zero, represents irrigation and/or rain (mm) and the estimated biomass accumulation rate (%).

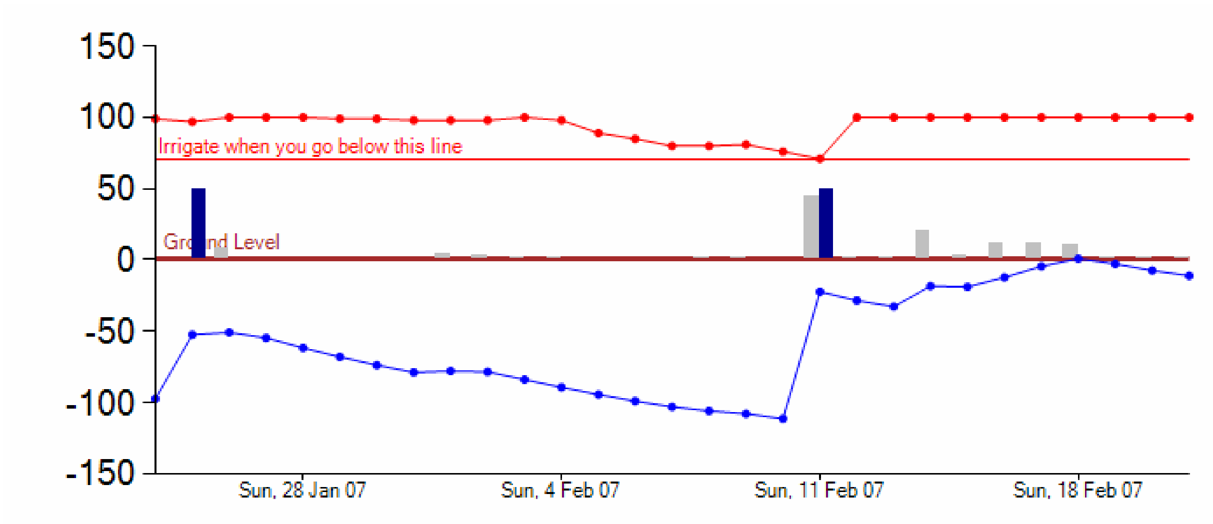


Fig. 3 WaterSense Irrigation Schedule

EVALUATION METHODOLOGY

During the peak growth period of 2007 (January to April) WaterSense derived soil water deficits and Sentak EnviroScan soil water content data was recorded to assess the reliability of WaterSense as an irrigation scheduling system. Data from three soil types with various plant available water content (PAWC) and irrigation methods *viz.* furrow, high pressure overhead (travelling gun) and low pressure overhead (travelling boom) were compared. Irrigation schedules were based on grower management decisions, volumes of applied irrigation were based on grower estimates and rainfall and critical daily climatic data was sourced from the nearest automatic weather station (AWS). However, as AWS's were located 0.5 to 6klm from the monitored sites, grower rainfall records were also included when available. Soil moisture was monitored in 30 minute intervals at each site with the EnviroScan capacitance sensors (Figure 5), four sensors were installed at different depths within each PVC access tube (probe). Four access probes with sensors located at 10cm, 30cm, 60cm and 100cm depths were placed near the cane stool 10 cane rows (15m) apart. EnviroScan soil water content recorded at midnight was integrated over a depth of 1 m to obtain and estimate of total water content to that depth. The water content after drainage (drained upper limit or DUL) was identified by noting the change in decline of water content after persistent heavy rains in February 2007. The WaterSense derived soil water deficit was the daily deficit for the potential root depth. Maximum rooting depths in WaterSense are those reported by Inman-Bamber *et al*., (2000).

Fig. 5 Sentek EnviroScan

The Bundaberg area soil survey (Zund *et al*., 1998) was used to classify soil characteristics for each site by Australian Soil Classification, Great Soil Group and PAWC (Table 2).

Table 2 Monitoring sites – soil types and PAWC - Bundaberg

Site	Irrigation Method	Soil type	Maximum Root Depth (m)	PAWC (mm)
A	Travelling Boom	Red Dermosol – Red podzolic	1.60	150
B	Furrow/Travelling Gun	Red Ferrosol – Krasnozem	1.30	185
C	Furrow	Red Dermosol – Euchrozem	1.60	175

IRRIGATION SCHEDULES

Public concern with the impact of climatic affects and water use practices on the environment has increased in recent years leading to greater pressure on individual landholders to develop practical management plans that demonstrate ecologically sustainable water use practices. A combination of EnviroScan and WaterSense provides a set of tools to plan and review irrigation practice and identify associated hazards and risks to individual farms and the off site environment.

How much irrigation to apply and how often to irrigate are important issues when establishing an effective land and water management strategy. A general rule of thumb encourages the landholder to operate an irrigation schedule that maintains the soil water within the readily available water content (RAWC) which is water readily usable to sugar cane. RAWC is defined as the difference between soil moisture when sugarcane internode elongation is maximum and soil moisture when elongation has declined to 50% of its maximum during a drying cycle (Zund and McDougall, 1997).

Table 3 RAWC for soils at three monitored sites

Site	Soil type	RAWC (mm)
A	Red Dermosol – Red podzolic	52-70
B	Red Ferrosol - Krasnozem	105
C	Red Dermosol - Euchrozem	70-87

RESULTS

DUL for the top 1 m of soil for sites a, b and c was 270, 400 and 300 mm respectively and DUL minus EnviroScan soil water content provided a measure of soil water deficit comparable with the water deficit simulated with WaterSense. These daily deficits are illustrated for the three monitored sites in Figures 6 which shows the extent of change in the deficit attributable to rain, irrigation and crop evapotranspiration (ET_C). Irrigation schedules applied to each monitoring site illustrate variability in implementation of best practice principals. At site A, soil water deficit was not allowed to exceed the maximum RAWC assumed for this soil (Table 3) and irrigation after the wet season was applied so as not to exceed DUL (Figure 6a). This led to effective use of both irrigation and rainfall in order to maximise crop growth with minimum runoff and drainage. The agreement between measured and simulated soil water deficit was excellent (Figure 6a). At site B the agreement between measured and simulated deficit was poor possibly because this soil is poorly drained and not well matched to the selection of soils in WaterSense. From the measured water balance it can be seen that irrigation and/or rainfall events exceeded DUL soil water content on several occasions and irrigation was applied when the deficit was approximately 50% of RAWC and as a result runoff and/or temporary waterlogging may have occurred. At site C, limited irrigation availability in the latter part of the monitored period prompted the grower to reduce the amount of water in each irrigation event and this deficit irrigation program maintained soil water within the lower level of the RAWC for much of the period. The agreement between measured and simulated soil water deficit was good after rain in February 'reset' the water balance. Under estimation of soil water content at the start of the cropping cycle may have contributed the poor agreement before the February rain.

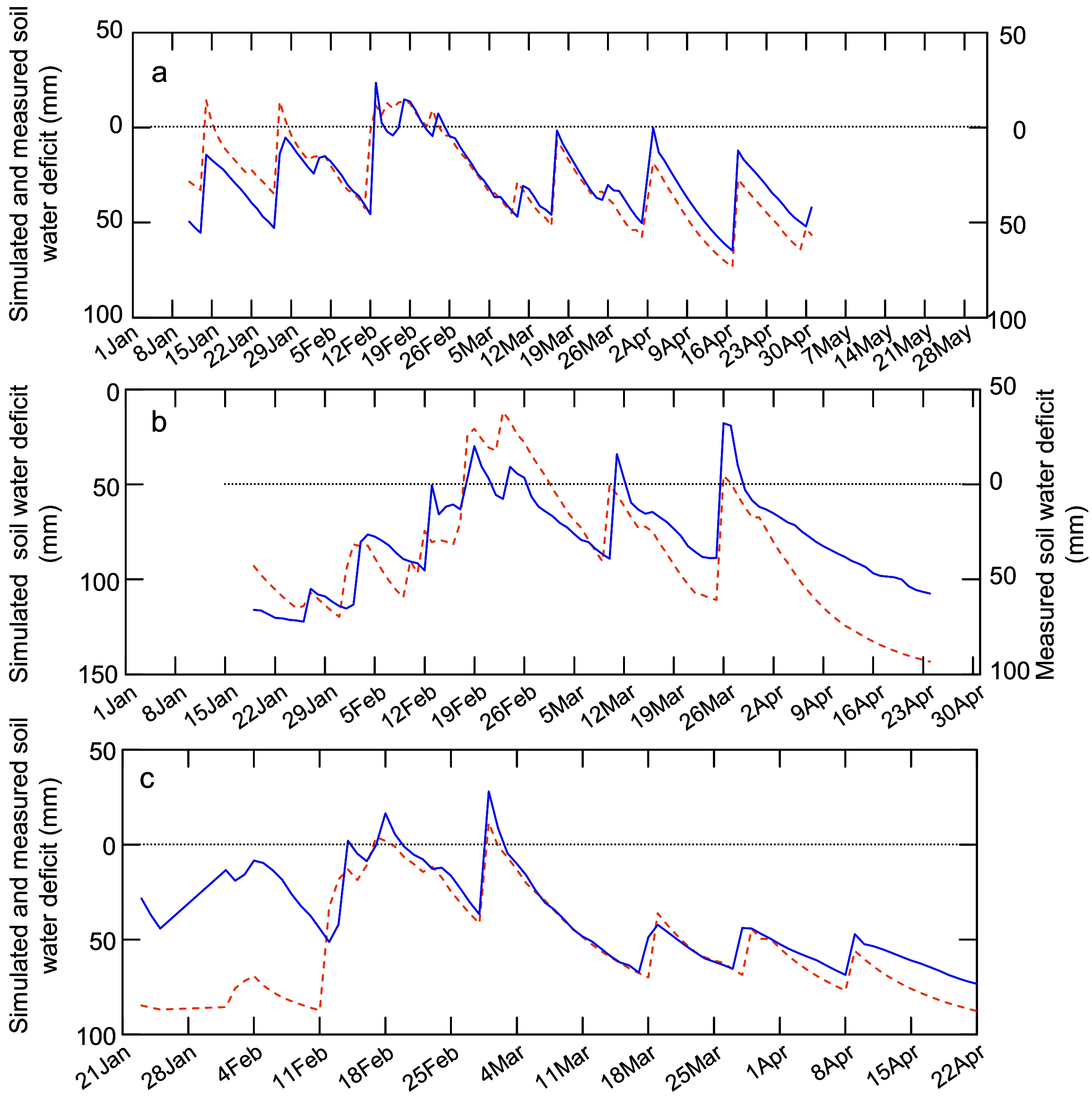


Figure 6. Simulated (---) and measured (—) soil water deficit for three paddocks of sugarcane (sites A, B and C) where soil moisture was monitored with capacitance sensors. Note the different range for site B.

DISCUSSION

The need for supplementary irrigation in sugarcane production at Bundaberg was clear more than a century ago. Continued use of the groundwater resource however induced lower water levels and salt water encroachment, and prompted moves for a replacement source of supply. This eventually occurred early in the 1970's with the commissioning of the Bundaberg Area Irrigation Scheme which included the building of three major water storages on Bundaberg district rivers, and provided sufficient water (both surface and groundwater) for supplementary irrigation in the Bundaberg district. Research, development and extension programs increased from midway through the 20th century resulting in an extensive understanding of factors effecting land, water and crop management which has been extended to the sugar cane growing community.

Most scheduling methods were based on the premise that irrigation practice refilled the soil profile in each event. This was useful where water is not limited but in regions where water supplies necessitate that irrigation is a supplement to rain, irrigation programs must then strive to achieve the highest possible return from a system based on deficit irrigation practice.

Introduction of capacitance monitoring systems highlighted the lack of capacity to reflect climatic influences on daily crop water use (ET_C) when estimating irrigation schedules based on long term average Class A pan x crop factor. The "real time" feature of the capacitance method enabled irrigators to develop best management strategies that maximised the productivity benefit of both rain and irrigation in conjunction with minimising the probability of runoff and/or drainage beyond the crop root zone. However, cost and management issues meant that only a limited number of capacitance units were established in the cane industry. Development of WaterSense provided an additional opportunity to utilise the influence of daily climatic factors to develop irrigation management strategies without the cost of field monitoring equipment.

Evidence presented here and elsewhere in these proceedings (Inman-Bamber et al., 2008) indicates good agreement between WaterSense and capacitance measurements in the representation of soil water content despite the use of default soil hydraulic properties in WaterSense rather than properties specific to the soils of the three sites. Anyone experienced in soil moisture measurements of any kind will know these vary even over short distances. However with soil moisture monitoring and simulation used together, we can learn more about our soils and crop responses to the water stored within.

Many growers plan whole farm irrigation schedules using monthly average Class A pan evaporation rates and estimates of pan factors. However it is difficult to accommodate variation in crop development and soil characteristics between individual paddocks with this method and there is a risk of both excessive or under irrigation occurring in some instances. In addition, daily and weekly variation in radiation, temperature, wind and humidity can lead to large differences between actual ET_C and monthly averages estimated from the Class A pan. A scheduling system based on long-term averages was developed for growers in the Ord irrigation scheme but failed because of short-term variation in the climate (Webb et al, 2006).

Scheduling with WaterSense can lead to substantially reduced irrigation compared to conventional scheduling (450 vs 700 mm), without losing yield at least in theory (Inman-Bamber et al., 2007). However field experiments demonstrated how irrigation scheduling based on WaterSense principles could save 100 to 300 mm without a loss in yield even in supplementary schemes. This is generally achieved by gradual exploitation of water deep in the soil profile which is eventually replenished during the wet season (Inman-Bamber et al., 2008).

In recent years, increased emphasis on best land and water management practice (BMP) has heightened the need for a crop water use interpretative system and an irrigation management tool with the capacity to enhance economic performance within BMP guidelines. WaterSense provides this tool and enhances the capacity of irrigators to optimize both limited and adequate irrigation water supplies to enhance productivity potential while limiting offsite impacts of irrigation to preserve the land and water resource for future generations.

CONCLUSION

Whether we are tracking crop water use impact on the soil water deficit or monitoring a fluctuating deficit that occurs during intermittent rainfall it is most important to ensure that valuable water resources are not committed to the crop earlier than is necessary but not delayed to the extent that crop productivity is affected. Capacitance monitoring systems such as EnviroScan have this "real time" ability but for the cane growing industry where individual growers may have multiple paddocks on several farms, the capital cost of this equipment and management issues associated with multiple probe sites and logger installations is often a deterrent to adoption of the technology.

WaterSense web based irrigation scheduling tool has the ability to provide similar "real time" management support to that of EnviroScan. Additionally, WaterSense has the capacity to illustrate inefficient practices and show options to achieve irrigation BMP. This holistic approach to irrigation, rainfall, drainage and runoff management encourages the grower to apply irrigation volumes according to the soil water holding capacity of individual paddocks, thus reducing the potential for applied volumes to exceed soil water holding content and minimizes impact on the off site environment by reducing the potential for irrigation runoff and/or infiltration beyond the crop root zone.

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