DEFICIT IRRIGATION IN SUGARCANE USING THE WATERSENSE SCHEDULING TOOL

N.G. Inman-Bamber[1,3], S.J. Attard[2,3], M.G. Haines[4] and A.I. Linedale[5]

[1]CSIRO, Sustainable Ecosystems, Townsville, [2]CSIRO, Sustainable Ecosystems, Brandon,[3]CRC Irrigation Futures-Tropical Zone. [4]Bundaberg Sugar Services Limited, Bundaberg, [5]BSES Limited Bundaberg

ABSTRACT

Rainfall contributes substantially to crop water requirement in all regions in the Australian sugar industry and in some regions like the Burdekin there is sufficient irrigation water supply to supplement rainfall to meet full crop water requirements. In many other regions, irrigation is available but water supply is insufficient to fully meet crop water demand. The results of experiments in full and limited irrigation regions are reported to illustrate how a web-enabled scheduling and water management service, called ‘WaterSense’, can help irrigators with various irrigation strategies to use limited and unlimited irrigation water supplies. In the full irrigation region (Burdekin) three strategies were applied to access varying amounts of water stored in the soil after the wet season and yields of >20 t sucrose/ha were obtained with as little as 349 mm of irrigation. The experiment in the limited irrigation region (Childers) demonstrated varying stress levels used by WaterSense to indicate when best to apply irrigation after rainfall. The data collected showed good agreement between simulated and measured soil water content. It is suggested that growers, advisors and researchers learn more about their soils and water availability by using WaterSense combined with soil water monitoring in order to increase soil water deficits over time to make better use of rainfall and enhance sucrose accumulation by allowing moderate plant water stress.

INTRODUCTION

Some 60% of the Australian sugarcane crop worth about $ 2 bn annually relies on irrigation in some form. Rainfall contributes substantially to crop water requirement in all regions. Scheduling irrigations appropriately with the rainfall is a difficult management problem for growers. This research was aimed to help growers optimise irrigation management under these conditions.

Growers in the Bundaberg-Isis region were involved in a research project where the crop modelling skills of a research team were compared with the skills of cooperating growers in getting the highest sugarcane yield out of variable and limited water allocations (Inman-Bamber *et al*., 2006). After three years of on-farm experimentation growers asked to have access to the model used to optimise water use through the season and a web service called ‘CaneOptimiser’, was provided.

The participatory style of research conducted in the Bundaberg-Isis region was also used with sugarcane growers in the Ord River Irrigation scheme. In this case a much simpler water balance was used to demonstrate how potential yields could be achieved by irrigating at safe deficits of 40 to 60 mm.

This web service (called ‘WaterBalance’) was demonstrated to Bundaberg growers to assess their interest in this type of assistance for scheduling with limited irrigation water supplies. The new format and speed appealed to them and we then proceeded to develop a new service (called ‘WaterSense’) which combined elements of the simple water balance for Ord growers with the optimising algorithms of Caneoptimser (Inman-Bamber *et al*., 2007).

In this paper we used some published and some new results of two past experiments to illustrate how WaterSense schedules irrigation to avoid unnecessary water stress in areas with limited irrigation supplies and how it can help to achieve potential yields in areas with full irrigation supplies, using less irrigation water than that required to meet daily water demand (deficit irrigation) by using water stored at depth in the soil.

METHODS

WaterSense

The issue addressed in the Bundaberg-Isis region was when best to apply limited amounts of irrigation. An optimisation procedure (CaneOptimiser) based on the APSIM-Sugarcane model (Keating *et al*., 1999) was developed for applying irrigation when most needed to limit yield loss due to water stress. The web pages required users to enter details such as the nearest automatic weather station (AWS), past irrigation dates and amounts, dates of planting, ratooning and harvesting, soil type and annual water allocation (Inman-Bamber *et al*., 2005). The optimising method selected a relative growth threshold based on the loss of yield that growers have to accept given their water allocation, climate and soil parameters. Irrigation was then scheduled to ensure that stress did not exceed this threshold, which changed through the season depending on how the current climate compared with the historical climate. CaneOptimiser required about 40 minutes to complete the optimisation for each paddock, which was unacceptably long for a web service.

Research on sugarcane growth and water use started in the Ord River Irrigation scheme in 1996. Research was based on concepts in the APSIM Sugarcane model, but the water use algorithms of APSIM were inadequate (Inman-Bamber *et al*., 2006) and had to be replaced by the reference evaporation (ET_0) and a crop factor approach based on the Penman-Monteith equation (Allen *et al*., 1998). Crop factors were determined by measuring crop evapotranspiration (ET_C) with the Bowen ratio energy balance technique (Inman-Bamber *et al*., 2006). Ord growers were involved in each of these developments and in the development of ‘WaterBalance’ (Webb *et al*., 2006).

The two earlier services were essentially combined to form a new service called ‘WaterSense’. CaneOptimiser, based on the APSIM-Sugar model, contributed the concepts for canopy development and soil water hydrology while WaterBalance contributed algorithms for ET_0 and crop factors. WaterSense now simulates canopy development and soil water processes as in APSIM-Sugarcane without requiring direct access to the APSIM model. Target stress levels for irrigation are currently developed off-line while funds are being sought to complete the optimisation procedure (and other improvements) on-line.

Scheduling experiment for water limited schemes

A small plot experiment with four replications was conducted on a 5th ratoon of Q170 sugarcane near Childers in Queensland. The 4th ratoon was harvested on 5 September 2002 and the 5th ratoon on 31 July 2003. The grower irrigated the whole experimental site on 12 September 2002 and managed the experimental block to his usual high standards for weed control and crop nutrition.

Four irrigation treatments were selected in conjunction with the Childers Rural Water Use Efficiency Initiative (RWUEI) committee;
1) A ‘Rainfed’ treatment was not irrigated apart from the initial irrigation of about 40 mm which was applied to all the treatments using a travelling sprinkler system.
2) A ‘Capped’ allocation of 2 ML/ha to be scheduled by CaneOptimiser.
3) A treatment was designed to mimic a typical allocation scenario of starting with an allocation of 2 ML/ha and then using additional water that may be announced by the water providers from time to time, the ‘Plus’ treatment.
4) A more liberal irrigation regime (‘Liberal’ treatment) managed by the grower to determine yield responses to additional water if this was available.

For scheduling by CaneOptimiser, essential elements of the experiment were captured in a configuration of the APSIM model. Soil details of a Red Kandosol were obtained from Inman-Bamber *et al*. (2000). Climate data pertaining to the trials were obtained from an automatic weather station (AWS) less than 1 km from the site. Rainfall was also measured automatically by mounting a rain gauge about 1 m above the canopy at the site. Long-term climate data were obtained from the SILO database of the Bureau of Meteorology.

Plots were 15 m long and 12 rows (18 m) wide. Irrigation was applied through trickle tape on the surface but each irrigation application was 30 to 40 mm at a time, which is more typical of the sprinkler systems used by growers. An EnviroSCAN (ES) system (Sentek Pty Ltd, Australia) was installed by inserting two tubes in each treatment. One tube was in the crop row and the other midway between rows, which were 1.5 m apart. Capacitance sensors were set at depths of 100, 200, 400, 600, 800 and 1000 mm. An additional tube was inserted to 3.0 m with sensors at 150, 200, 250 and 280 cm in the rainfed plot to determine the full extent of the root system.

Scheduling experiment for full water supply schemes

An experiment conducted at CSR's Kalamia Estate near Ayr in the Burdekin, was fully described by Inman-Bamber and Attard (2008) and will be described only briefly here.

A plant crop of Q96 sugarcane was harvested green on 25 September 2000. Fertiliser was applied shortly after harvesting. The experimental site was divided into 12 plots, 3 treatments with 4 replications. Each plot consisted of nine rows, 1.52 m apart and 39 m long. Six rows were irrigated with surface trickle tape leaving three unirrigated rows between treatments to minimise interference between treatments. All plant and soil measurements were taken from the four inner irrigated rows.

Three irrigation regimes were compared once the crop was fully established. Two treatments were irrigated 1-3 times a week to replace water used at an estimated rate of 1.25ET_0 in one treatment, and at a rate of 1.00ET_0 in the other treatment in order to confirm previous research which indicated that the crop factor was 1.25 after canopy closure (Inman-Bamber and McGlinchey, 2003). It was anticipated that the 1.25ET_0 regime would maintain soil water deficit in the 30 to 50 mm range while the 1.00ET_0 treatment would result in a gradual increase in soil water deficit. The third treatment ('Furrow') was intended to approximate a furrow irrigation regime by providing more than 70 mm water through the tape when a deficit of about 70 mm had developed. This deficit was calculated using 1.25ET_0.

Yield measurements

Both experiments were sampled twice to determine various components of yield and crop development following the procedure of Muchow *et al.* (1993). On each occasion all plant material from a 15 m^2 quadrat in each plot was cut and weighed. A sub-sample of 15 shoots or stalks was partitioned into leaves, cabbage, millable stalk and trash. These components were weighed and then dried. Stalks were fibrated using a cutter grinder. Juice was expressed from the fibrated material, filtered then passed through a saccharimeter for brix and pol analysis.

RESULTS

Scheduling experiment for water limited schemes

WaterSense simulation of the Childers experiment

The first priority for use of limited water was to achieve good crop establishment with the first irrigation which was applied soon after harvesting the 4th ratoon in all treatments. By mid December, in-crop rainfall (120 mm) was less than half the long term mean (LTM) for that period (259 mm) and the model selected a moderate target of 75% of potential biomass accumulation for the second irrigation (Figure 1). Rainfall for the next three weeks was closer to the LTM (63 v 88 mm) and the model selected a less severe stress target (80%) for the third irrigation. Rainfall for January was nil and the model then decreased the stress target to about 72 % for the fourth irrigation and to less than 65% for the fifth irrigation. However 152 mm rain fell in early February which prevented biomass accumulation falling below 65% of potential. Rainfall for the period between the fourth and fifth irrigation (417 mm) exceeded the LTM (337 mm) and so the sixth irrigation was applied as soon as stress was indicated by the model (Figure 1). Drying off was planned for the 6-week period prior to harvesting and estimated stress levels dropped appropriately for increased sucrose content (Robertson and Donaldson, 1998). The grower also required a dry soil surface to prevent soil compaction from harvesting machinery.

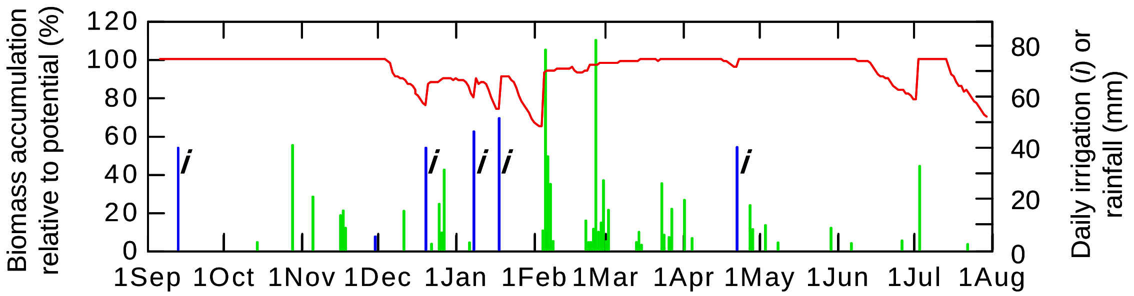

Figure 1. Biomass accumulation prior to irrigation or rain relative to potential, and daily irrigation (*i*) or rainfall for the ‘Capped’ treatment of Childers experiment in 2002/03.

The Plus treatment was irrigated in a similar manner except that two additional irrigations were applied on 29 November 2002 and 14 May 2003 when the water provider announced that excess water could be used. WaterSense treated these irrigations like rain and adjusted the stress thresholds upwards (data not shown). The Liberal treatment received an additional irrigation on 15 March 2003 even though WaterSense indicated no loss in biomass accumulation due to water stress.

Soil water deficits

The agreement between soil water deficit derived from WaterSense and the soil water content derived from the capacitance sensors was excellent for the Rainfed treatment, was reasonable for the Capped treatment but was poor for the Plus and Liberal treatments (Figure 2). Readings from access tubes in the row and interrow were distinctly different in all treatments (data not shown) and it is possible that the average of both positions did not accurately represent soil water content of the whole plot. Irrigation water was concentrated on the crop row through emitters spaced 60 cm apart so the capacitance sensors may not have detected the uneven wetting pattern in a way that could be compared with the WaterSense estimates of soil water deficit. This would account for the convergence between measured and simulated water content with decreasing irrigation over the four treatments.

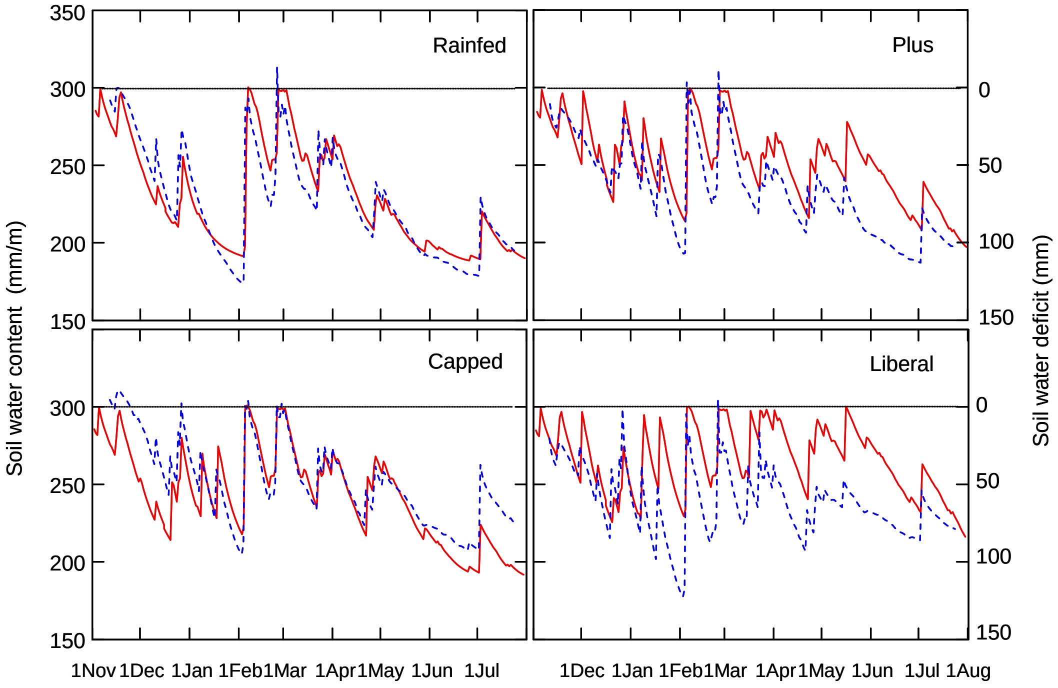

Figure 2. Water content average of row and interrow capacitance sensors in 1 m of soil (- - -) and soil water deficit to 1 m (——) derived from WaterSense for four treatments in the Childers experiment during 2002/03

Large deficits (>100 mm) developed in the Rainfed treatment and to a lesser extent in the capped treatment. According to WaterSense the deficit did not exceed 75 mm in the Liberal treatment until the end of the drying-off period prior to harvesting.

Crop yield components

Treatment effects on all crop attributes measured on 27 April and 29 July 2003 were either not statistically significant or were not related to increased irrigation except for the attribute of green leaves per stalk which is an indicator of water stress (Table 1). Increased irrigation may have exacerbated lodging which has been shown to limit cane and sucrose yield (Singh *et al*., 2002) but there was little evidence of lodging when the crop was sampled in April and yet yields were similar in all treatments.

Table 1. Crop yield components for the Childers experiment for two sampling dates.

Date	Component	Treatments				LSD (p=0.05)
		Rain	Capped	Plus	Liberal	
27 April 2003	Irrigation to date (mm)	40	223	261	295	
	Green leaves per stalk	5.8	6.3	6.6	6.0	0.2
	Cane yield (t/ha)	93	97	99	96	NS
	Sucrose %	5.3	6.3	5.8	5.2	0.8
	Lodge angle (deg)	11	19	16	13	NS
	Sucrose yield (t/ha)	5.0	6.1	5.6	5.2	NS
29 July 2003	Total irrigation (mm)	40	223	301	335	
	Green leaves per stalk	5.6	7.8	5.6	5.4	1.5
	Cane yield (t/ha)	105	112	104	103	NS
	Sucrose %	13.3	13.8	12.2	13.7	0.7
	Lodge angle (deg)	30	48	45	57	NS
	Sucrose yield (t/ha)	14.0	15.4	12.6	14.2	NS

Cumulative rainfall received by the crop was 619 mm on 27 April and 699 mm on 29 July 2003. Cumulative potential ET_C estimated by WaterSense was 907 and 1138 mm for the same periods respectively, so the lack of response to irrigation was surprising and was possibly due to water extraction by roots as deep, or deeper than the lowest capacitance sensor at 2.8 m. Readings from sensors at depths below 1 m indicated that roots were active to at least 2.8 m when the soil surface dried out but were inactive when even small amounts of rain occurred (Smith *et al*., 2005). Crop water index was remarkably high for the rainfed treatment (14.2 t cane per 100 mm rain plus irrigation) without deducting runoff and drainage which no doubt occurred when daily rainfall exceeded 100 mm two occasions (Figure 1).

Scheduling experiment for full water supply schemes

A total of 793 mm rain was received for the duration of the crop, the $1.00ET_0$ treatment received a total of 349 mm irrigation, the $1.25ET_0$ treatment received 508 mm and the furrow treatment received 672 mm irrigation (Figure 3a). The difference in irrigation between the $1.00ET_0$ and $125ET_0$ treatments was 46% and not 25% because the schedules were often interrupted by rainfall.

WaterSense indicated that the soil water deficit in the top 1 m of soil for all treatments, reached about 100 mm in mid-February during an unusual dry period in the wet season (Figure 3b). An irrigation in mid January for the Furrow treatment failed to fill the profile as was intended. The deficit remained high in the $1.25ET_0$ and $1.00ET_0$ treatments until mid March when 45 mm rain was received. The deficit was very high for the $1.00ET_0$ treatment for the rest of the experiment and all deficits were high after drying-off prior to harvesting.

WaterSense indicated only limited loss in biomass accumulation for the Furrow and $1.25ET_0$ treatments until drying-off in June and it indicated that the crop in the $1.00ET_0$ treatment was stressed and biomass accumulation was somewhat reduced throughout the period February to May (Figure 3c).

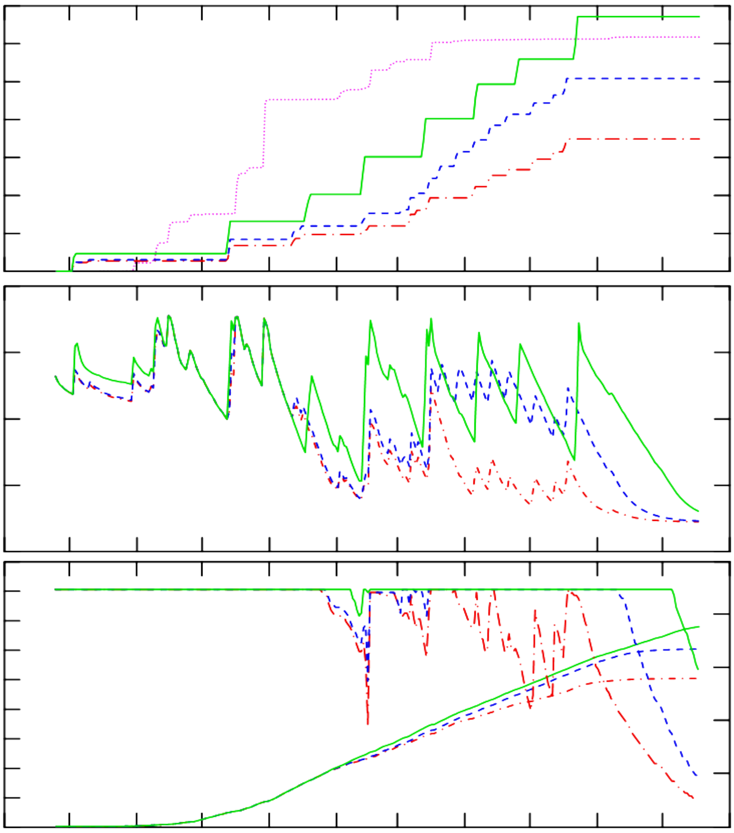

Figure 3. Cumulative rainfall (·····) and irrigation (a), simulated soil water deficit (b), biomass accumulation prior to irrigation or rain relative to potential, and simulated biomass (c) for the 1.00ET$_0$ (—▪—), 1.25ET$_0$ (---) and Furrow (——) treatments of the Burdekin scheduling experiment conducted during 2000/2001.

Table 2. Treatment means and statistical significance (*P=0.05, **P=0.01) for results of plant sampling on 10 April and 17 July 2001 (after Inman-Bamber and Attard, 2008)

Sampling date	**10 Apr 2001**			**17 Jul 2001**			**10 Apr**	**17 Jul**
Treatments	1.00ET$_0$	1.25ET$_0$	Furrow	1.00ET$_0$	1.25ET$_0$	Furrow	Significance	
Irrigation (mm)	223	346	493	349	508	671		
Crop attributes								
Green leaf number per stalk	7.6	9.5	10.9	6.0	8.6	8.9	**	*
Leaf area index	1.5	3.8	2.3	2.9	3.6	3.6	**	NS
Stalk DM content (%)	0.264	0.237	0.252	0.305	0.319	0.331	**	NS
Sucrose content (%)	0.111	0.087	0.091	0.145	0.148	0.147	**	NS
Cane yield (t/ha)	109	120	117	141	142	137	**	NS
Dry biomass yield (t/ha)	40.7	39.9	41.9	56.9	60.0	59.2	**	NS
Sucrose yield (t/ha)	12.1	10.4	10.6	20.3	21.1	20.1	**	NS

While WaterSense is not a detailed physiological growth model, the biomass estimates (41 – 45 t/ha) were similar to measured biomass (41 – 42 t/ha) in April. In July, measured and simulated biomass was similar (57 and 56 t/ha respectively) for the 1.00ET$_0$ treatment, 60 vs 66 t/ha for the 1.25ET$_0$ treatment and 59 vs 75 t/ha for the Furrow treatment (Figure 3 and Table 2). Measured yields of biomass, cane and sucrose were not affected significantly by irrigation treatment in July but sucrose yield was significantly greater in the 1.00ET$_0$ treatment than for the other treatments in April. This was due to substantially greater sucrose content in the low irrigation treatment compared to the wetter treatments. The higher sucrose content, reduced green leaf number per stalk, reduced leaf area index and greater stalk dry matter content were all indicative of a moderate level of stress appropriate for enhancing sucrose content (Inman-Bamber *et al*., 2008). Apart from green leaf numbers, differences in these indicators of stress were absent in July because all treatments were dried-off appropriately.

WaterSense was designed to cope with differential response of leaf growth and photosynthesis to water stress but not with complex effects of water stress on dry matter partitioning which no doubt were responsible for some of the responses in Table 2 (Inman-Bamber at al., 2008).

Examples of WaterSense output for limited and full irrigation schemes

Figure 4 presents graphical displays from WaterSense indicating a typical irrigation schedule in a system with limited water supplies and in a full irrigation system. In the example of a limited system, irrigation was scheduled when yield accumulation between irrigations started to decline below a target level of stress which was set at 99% in order to achieve potential yields with the minimum amount of water. The more limited the allocation the lower this target would be. In the example of a full irrigation schedule, water was applied at a set soil water deficit which is normally equivalent to the amount of readily available water assumed to be held in the root zone.

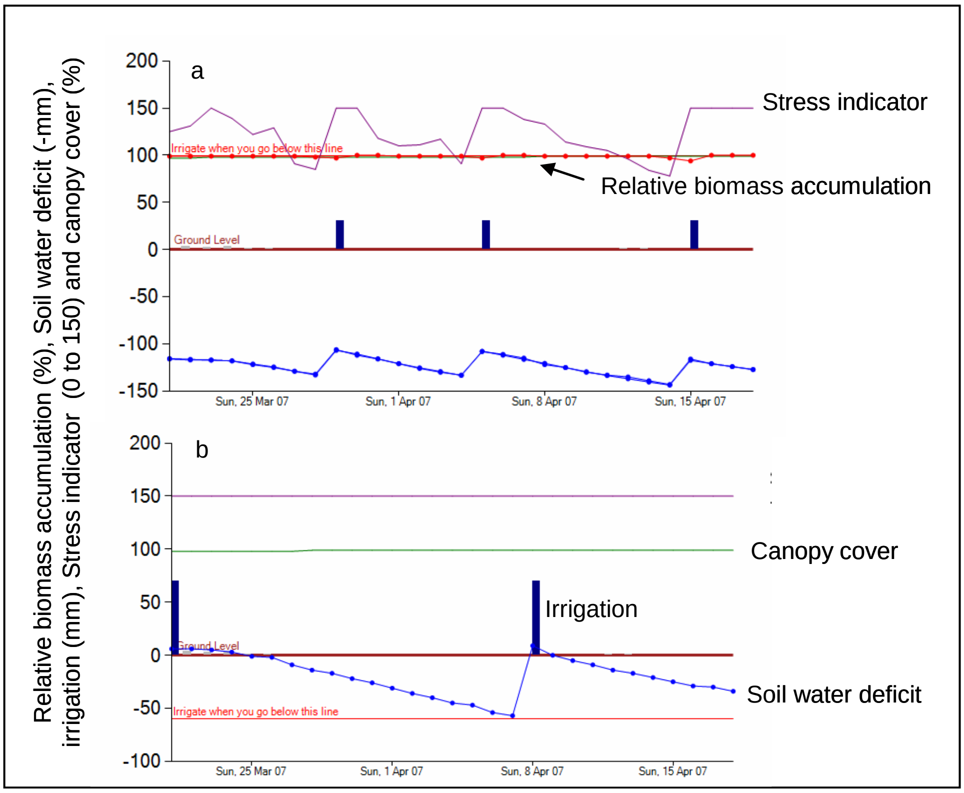

Figure 4. Graphical displays from WaterSense for a limited irrigation system (a) and a full system (b). The water stress indicator (purple) indicates no stress when = 150, indicates limited leaf growth when 100-150, and below 100 indicates reduced photosynthesis.

DISCUSSION

With limited irrigation water supply it is difficult to know what yield losses, if any, to plan for in an irrigation schedule because of uncertainty about future rainfall and future changes in allocation. WaterSense was developed to help growers with these uncertainties to plan irrigation through the season by working out the most likely water stress scenario associated with a given allocation, soil type, planting or ratoon date and past rainfall and irrigation. The Childers experiment was conducted along with other experiments in the region to demonstrate to growers how WaterSense worked and to prove that the tool could help deliver the greatest benefit from limited and complex water supplies in the region (Inman-Bamber *et al.*, 2005).

Development of stress (relating to biomass accumulation) in the capped treatment, indicated how the current web based version of WaterSense would have scheduled irrigation in the Childers experiment although the APSIM based program was used at the time. Validity of the current version was demonstrated through close agreement between measured and simulated soil water deficit of the rainfed and capped treatments. It is noteworthy that the two Y scales in Figure 2 are identical indicating that the EnviroSCAN system was calibrated well enough to account for vertical water fluxes based on accurate rainfall measurements at least for the rainfed treatment.

Lessons from limited irrigation systems can be applied to full irrigation schemes where water is likely to become more expensive and more highly regulated in future. WaterSense can help growers to reduce water use firstly by scheduling only as much and as often to meet crop water demand without risking loss in yield as in the 1.25ET_0 treatment of the Kalamia experiment and in the full irrigation mode of WaterSense (Figure 4b). A second but more risky approach is to provide less water than the crop actually needs and allow roots to take up the balance from water stored deep in the profile as in the 1.00ET_0 treatment and in the limited water mode of WaterSense (Figure 4a). In the Kalamia experiment on 4 July 2001, soil water content at a depth of 135 cm was 23 and 31 % for the 1.00ET_0 and 1.25ET_0 treatments respectively indicating the extent to which deep water extraction had contributed to water required by the 1.00ET_0 treatment (Inman-Bamber and Attard, 2008). A third approach is to actually aim for reduced biomass yield as is necessary for growers with limited water, knowing the capacity of the crop to compensate by redistribution of dry matter in favour of sucrose accumulation. This was demonstrated in the results of the April sampling in the Kalamia experiment and in previous field and glasshouse experiments (Inman-Bamber *et al.*, 2008).

The lack of yield response in the Childers experiment was thought to be due to deep water extraction but another possibility is that older ratoons use less water and produce less biomass than younger ratoons. If the crop factor was 1.00 and not 1.25, for example, WaterSense would predict similar biomass yields for the three irrigation treatments of the Childers experiment. Of course a combination of deep water extraction and reduced crop factor could have explained the observation as well.

It is suggested that growers, advisors and researchers learn more about their soils and water availability by using WaterSense combined with soil water monitoring in order to increase soil water deficits over time to make better use of rainfall and knowledge of sucrose accumulation under moderate stress.

ACKNOWLEGEMENTS

We are grateful to CSR Kalamia and Mr Graham Webb for allocating land for this research project and to John and Christine Wilcox and the Childers RWUEI committee for practical help and support. Staff of the Technical Field Dept at CSR, Kalamia mill, are thanked for their dedication and hard work in the field. Funding for this project was provided by the sugar industry and the Commonwealth Government of Australia through SRDC, and is gratefully acknowledged.

REFERENCES

Allen, R.G., Periera, L.S, Raes, D. and Smith, M. (1998). Crop evapotranspiration - Guidelines for computing crop water requirements. FAO Irrigation and drainage paper 56. FAO, Rome.

Inman-Bamber, N.G. and McGlinchey, M.G. (2003). Crop coefficients and water-use estimates for sugarcane based on long-term Bowen ratio energy balance measurements. Field Crops Research, **83**,125-138.

N.G. Inman-Bamber and S.J. Attard (2008). Water savings and water accounting in irrigated sugarcane. Proc. Aust. Soc. Sugar Cane Technol., **30** (in press).

Inman-Bamber, N.G., Zund, P.R. and Muchow, R.C. (2000). Water use efficiency and soil water availability for sugarcane. Proc. Aust. Soc. Sugar Cane Technol., **22**, 264-269.

Inman-Bamber. N.G., Attard, S.J., Baillie, C., Lawson, D. and Simpson, L. (2005). A web-based system for planning use of limited irrigation water in sugarcane. Proc. Aust. Soc. Sugar Cane Technol., **27**, 170-181.

Inman-Bamber, N.G., Webb, W.A. and Verrall, S.A. (2006). Participatory irrigation research and scheduling in the Ord: R&D. Proc. Aust. Soc. Sugar Cane Technol., **28**, 155-163.

Inman-Bamber, N.G., Attard, S.J., Verrall, S.A., Webb, W.A. and Baillie, C. (2007).
A web-based system for scheduling irrigation in sugarcane. Proc. Int. Soc. Sugar Cane Technol., 26, CDROM.

Inman-Bamber, N. G., Bonnett, G. D., Spillman, M. F., Hewitt, M. L. and Jackson, J. (2008). Increasing sucrose accumulation in sugarcane by manipulating leaf extension and photosynthesis with irrigation. Australian Journal of Agricultural Research, **59**, 13 – 26.

Keating, B.A., Robertson, M.J., Muchow, R.C. and Huth, N.I. (1999). Modelling sugarcane production systems. I. Description and validation of the APSIM Sugarcane module. Field Crops Research, **61**, 253-271.

Muchow, R. C., Wood, A. W., Spillman, M. F., Robertson, M. J., and Thomas, M. R. (1993). Field techniques to quantify the yield-determining processes in sugarcane. I. Methodology. Proc. Aust. Soc. Sugar Cane Technol., **15**, 336-343.

Robertson, M. J. and Donaldson, R. A. (1998). Changes in the components of cane and sucrose yield in response to drying-off before harvest. Field Crops Research, **55**, 201-208.

Singh, G., Chapman, S.C., Jackson, P.A. and Lawn, R.J. (2002). Lodging reduces sucrose accumulation of sugarcane in the wet and dry tropics. Aust. J. Agric. Res., **53**, 1183-1195.

Smith, D.M., Inman-Bamber, N.G. and Thorburn, P.J. (2005). Growth and Function of the Sugarcane Root System. Field Crops Research, **92**, 169-184.

Webb, W.A., Inman-Bamber, N.G. and Mock, P. (2006). Participatory irrigation research and scheduling in the Ord: Extension. Proc. Aust. Soc. Sugar Cane Technol., **28**, 164-172.