Modelling water stress response in sugarcane: Validation and application of the APSIM-Sugarcane model.

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ABSTRACT

The APSIM-Sugarcane model is being used increasingly in the Australian sugar industry to benchmark water use efficiency and productivity. The model has potential to contribute substantially to optimising water use in supplementary irrigation regions. While simulation capability of APSIM-Sugarcane has been demonstrated for a large number of conditions in various countries, there has been little detailed validation of the processes involved in crop response to water stress. This paper compares measured and simulated processes such as canopy development, root water extraction, dry matter and sucrose accumulation, in order to demonstrate simulation capability of response to water stress. The model is then used with long-term climate records to determine optimum timing of limited irrigation in Bundaberg.

INTRODUCTION

Water use for agriculture in Australia is subject to increasing scrutiny from policy makers and environmentalists, and the sugar industry is under increasing pressure to demonstrate that water use is both efficient and economically worthwhile. The APSIM-Sugarcane model has been used recently to determine effective rainfall, irrigation requirement, water use efficiency, optimum on-farm storage capacity and best bet irrigation strategies with limited water (2,4). While the model has been subjected to comprehensive testing in a number of countries and growing conditions (4), the attention given to processes responsible for yield reduction due to water stress, has been limited. In this paper, we compare key elements of sugarcane response to water stress in experiments where varying levels of water stress were imposed, in order to demonstrate simulation capability of response to water stress. We then consider how the model will be used assist to growers in the Bundaberg region to apply their annual allocations of water in the best way.

MATERIALS AND METHODS

Field plot experiment

Three experiments (1, 2 and 3) conducted in one field at CSR Kalamia Estate, Ayr, Australia (19.57°S, 147.4 °E) reported by Robertson et al. (7), were further analysed and simulated with the APSIM-Sugarcane model. The soil was a duplex clay loam (0-300 mm) over coarse sand (300-1500 mm). Experiments 1 and 2 were conducted on plant and ratoon cycles of the same crop of Q96. Sufficient water was applied with each irrigation to return soil water content of the root zone at least to the drained upper limit (DUL). An early-season (ES) stress treatment was designed to impose stress during tillering and a mid-season stress (MS) was intended to span the start of stalk elongation (7). There were four replicates. In experiment 3, a first ratoon crop of Q96 was irrigated for the first two months and then irrigation was withheld for 70, 117, 126, 138, 146, 167, 182, 207 or 239 days from unreplicated plots. Green leaf area index (LAI), aboveground biomass and its components were determined following the procedure described by Muchow et al. (6). Soil water content from 200 to 1500 mm was measured by neutron probe, with the 0-200 mm layer determined gravimetrically. The probe was calibrated with soil samples taken at the time of installation of the access tubes. Bulk density (BD) was determined by coring.

Simulation of field plot experiments

The ‘Manager’ module of the APSIM model v 1.6 was configured to mimic all field operations pertaining to the three experiments including planting, fertiliser application, hilling-up, irrigation, burning and harvesting as described by Robertson et al (7). Parameters for the 'Sugar' module were those supplied with the software (defaults). Parameters for the 'Soilwat2' module were measured or adjusted to represent the soil of the experimental site. The drainage coefficient was set to 0.5 and 0.9 for the clay and sand horizons respectively. The maximum fraction of available soil water that can be extracted in a day (*kl*) was determined by fitting soil water content (SWC) to an exponential decay function of time (eq .1)

Where $t\text{-}t_o$

is the duration (days) of the exponential decay, which starts in a layer at time t_0

$$SWC = LL + (DUL - LL)\ \exp(-kl(t - t_o)) \qquad (1)$$

Long-term simulations

Sugar module parameters were the same as for those used to simulate the field experiments at Ayr. Soil parameters were for a Bundaberg red dermosol (3). Temperature and radiation data from 1/1/1957 to 31/12/1998 were obtained from Datadrill (S.J. Jeffrey pers. Comm.). Temperature data between 1/1/1887 and 31/12/1956 were derived by adjusting Brisbane temperature for differences between Bundaberg and Brisbane. Radiation was then generated for the same period using the method of Bristow and Campbell (1). Rainfall data was recorded by the Bureau of Meteorological for station number 39037 (Fairymead, Bundaberg). A crop ratooning in mid August after green trash blanketing and after an initial irrigation of 24 mm, was selected as a case study. The best time to apply four more irrigations of 44 mm each, was determined by irrigating at a range of 'stress levels' and then selecting the strategy that gave the highest yield and that used all the allocated water (200 mm). Stress levels were determined as the cumulative loss in biomass due to water stress. Thus for a 0.9 stress level, irrigation was triggered after water stress reduced growth to 0.9 of potential growth since the onset of stress. Accumulation of yield loss was cancelled after >20 mm rain or irrigation. Stress levels of 0.1,0.2 to 0.9 were simulated. A minimum 10-d irrigation cycle was imposed. Drying-off was simulated by precluding irrigation from 5 July to 15 August.

RESULTS

Plant available soil water and root water extraction

The difference in SWC to a depth of 1500 mm, after irrigation and after the most severe stress treatment, was 70 mm and this was regarded as plant available soil water capacity (PAWC=DUL-LL) for this soil. Coarse sand below 300 mm was responsible for this low PAWC. Equation 1 was fitted to SWC measured at six depth intervals (3 x 200 mm, 3 x 300 mm) resulting in kl values of 0.100, 0.063, 0.049, 0.055, 0.064 and 0.086 for successive soil depths. Simulated available water (AW) in the soil profile was mostly within one standard error of mean measured AW (Fig. 1).

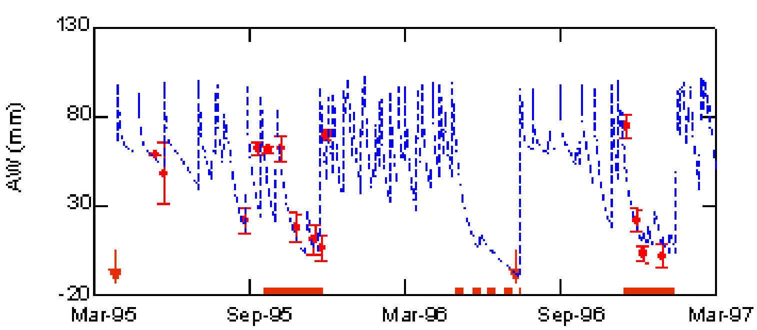

Figure 1. Measured (symbols) and simulated (line) available water (AW) during a plant and a ratoon crop of Q96 (experiments 1 and 2) which were denied irrigation during mid-season (MS treatment). X-axis is thickened to show stress periods (solid) and a drying off period (broken). Bars show mean ? one standard error. Arrows show planting and ratoon dates respectively.

Leaf area index (LAI), stalk yield and sucrose yield

Model simulations of LAI of experiments 1 and 2 were mostly within one or two times the standard error of the mean LAI (Fig 2a, b, c). The model failed to account for loss of LAI towards harvest when lodging reduced LAI. Stalk yield (dry mass) of experiment 1 and 2 was also predicted reasonably well (Fig 2d,e,f). The model simulated the start of stalk growth too early in each of the six crops in experiments 1 and 2 (Fig 2). The response in stalk yield at harvest (357 days after ratooning) to various irrigation free periods in experiment 3, was simulated accurately but there was some discrepancy between measured and simulated yields at 258 days (Fig 3a). Simulated and measured sucrose yields in experiments 1 and 2 were closely correlated (Fig 3b) as were simulated (Y) and measured (X) sucrose yields in experiment 3 (Y= 0.65 + 0.957X, n= 17, R^2 = 0.92, standard error of estimate = 1.3 t ha^{-1}).

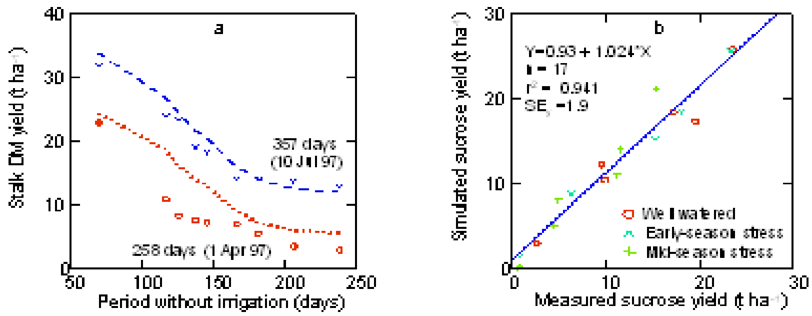

Figure 2. Measured (dots) and simulated (lines) leaf area index (a,b,c) and stalk yield (d,e,f) in well watered (a,d) , early stress (b,e) and mid-season stress (c,f) treatments applied in experiment 1 and 2. X-axis is thickened to show periods when irrigation was denied to impose water stress treatments. Bars show mean ? standard error of mean

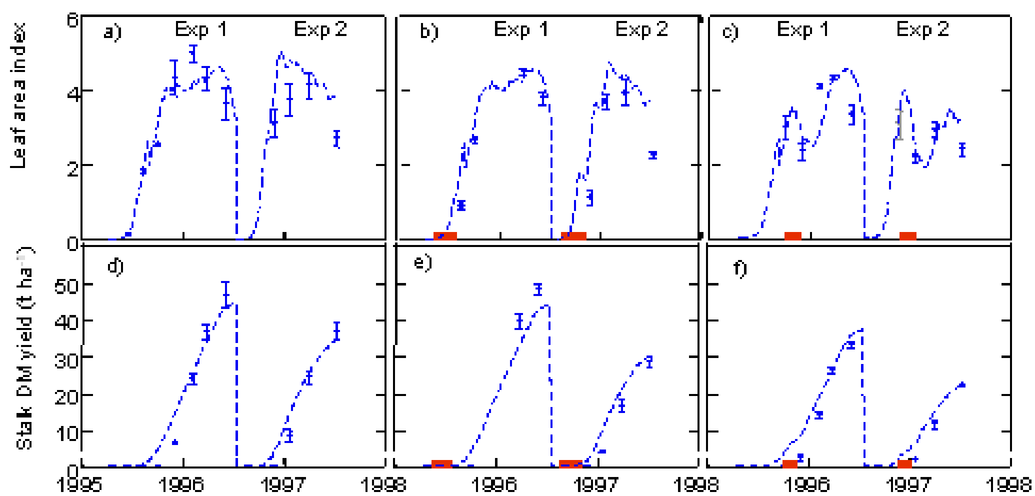

Figure 3. a) Simulated (lines) and measured (symbols) stalk dry mass in experiment 3 where nine stress periods were imposed, b) Simulated and measured sucrose yield in experiments 1 and 2.

Optimum use of 200 mm irrigation at Bundaberg

Long-term simulations indicated that an initial irrigation of 24 mm was required in 103 out of 110 years and exactly 200 mm was applied only in these years. Of the 103 years, the remaining four applications of 44 mm were best used in 14-d periods as shown in Fig 4a. Best use of 200 mm never included irrigation before 27 September for El Nino years or before 11 October in other years. The best strategies (giving the highest yields) used applications most frequently between 8 November and 17 January for all years. During late October to early December, there was more irrigation used in El Nino than in non El Nino years. Irrigating at the mildest stress level (0.9) was the most successful strategy in non El Nino years. The strategy was successful less often in El Nino years. Stress levels of 0.9, 0.7 and 0.6 were best in these years. It was never necessary to allow severe stress (<0.4) to develop in this soil, with 200 mm irrigation.

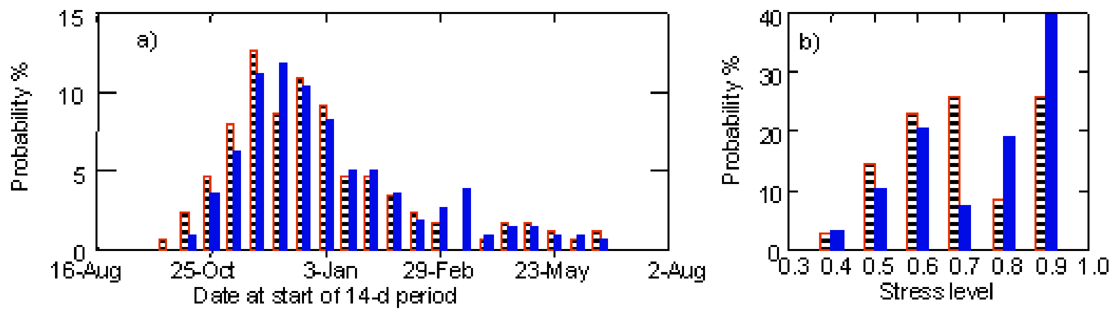

Figure 4. Probability of best 14-d periods (a) and best stress level (b) for the use four irrigations of 44 mm per crop. Hatched bars are for El Nino years and solid bars are for other years.

CONCLUSIONS

The results demonstrated that the default settings of version 1.6 of the APSIM model could account for a large number of observations on the effect of water stress on stalk and sugar yield in the three experiments at Ayr. The model was able to mimic the graded response of experiment 3 as well as responses to stress imposed by withholding irrigation in early and mid-season development. Errors in predicting LAI at values greater than 3.0, did not seriously affect yield prediction because more than 2/3 of incident radiation is intercepted at LAI=3.0 (4). It was important to measure PAWC and *kl* accurately for a successful validation of the model. PAWC in particular had a marked effect on yield predictions in water limiting conditions in previous work with APSIM (4). Long-term simulations with APSIM-Sugarcane indicated that a limited allocation of irrigation (200 mm) in Bundaberg would best be used between mid-November and mid-January in most years. In El Nino years there was a tendency to use this water earlier than in other years. For the conditions of the case study, irrigation should be applied at stress levels>0.7 in the majority of non El Nino years and at levels 0.5 to 0.7 in the majority of El Nino years. Optimum stress levels may be different for other soils and other cropping cycles. APSIM could be used to determine best timing of limited irrigation for each season, once a stress level is selected. Climate forecasting indicators like sea surface temperatures (El Nino) or the Southern Oscillation Index could further refine predictions for best use of limited water.

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