SHORT COMMUNICATION

ASSESSMENT OF THE FEASIBILITY OF USING STALK DIAMETER FLUCTUATIONS FOR AUTOMATED CENTRE PIVOT IRRIGATION SCHEDULING OF SUGARCANE IN ZIMBABWE

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Abstract

The feasibility of a partial automatic irrigation scheduling technique for sugarcane was developed and tested against three independent methods namely: (i) the growers' current irrigation practice, based on class A-pan measurements, (ii) a climate-based approach using the ZIMsched model irrigation charts and (iii) the modified class A-pan method, using site-specific pan coefficients. The automated scheduling treatment was fitted with a relay to trigger irrigation when soil moisture reached a predetermined threshold. The threshold was determined from analysing diurnal evolution (DE) and maximum daily shrinkage (MDS) of cane stalk measurements using dendrometers. Soil moisture depletion was measured with moisture probes placed in the root zone of the cane and connected to a data logger. Treatment effects were assessed based on the water applied, power used, cane height, and yield. For the three-month period of observation from 16 December 2006 to 18 March 2007, the automated method used 9.2% less water than the growers' current class A-pan irrigation schedule, while the ZIMsched charts and the modified class A-pan used 22.4% and 10.4% more water than the control, respectively. Automatic scheduling did not reduce the cane yield, while savings on water and power were made. Irrigation efficiency was improved significantly by reducing deep percolation. Dendrometers showed great potential as a tool that can be used for stress monitoring in sugarcane plants, and hence irrigation control.

Keywords: sugarcane, irrigation, irrigation scheduling, class A-pan, ZIMsched model, stalk diameter, dendrometer, centre pivot

Introduction

The sugar industry in the Lowveld of Zimbabwe is entirely dependent on irrigation water to produce a viable crop. Water-saving agricultural practices and sound water management strategies are therefore urgently required to ensure the long-term viability of the industry. Automation of centre pivot irrigation systems has a promise of providing greater control over the quantity of water applied and thus potentially improving water use efficiency. Automated irrigation scheduling systems require the use of soil, crop, or environmental sensors to determine the need for irrigation and then either a controller or a computer to control the irrigation sequence (Klein, 2004; Jones, 2004). An approach to irrigation scheduling with considerable promise is to measure a property of the crop itself, which responds to water stress. One possible indicator for sugarcane is stalk diameter, which not only increases steadily as the crop develops, but also shows a diurnal increase and decrease (Goldhamer and Fereres, 2003; Nortes *et al.*, 2005; Garcìa-Orellana *et al.*, 2007). The work reported here is the first stage of a project to develop an automatic irrigation scheduling technique in centre pivot irrigation systems. This study focused on the use of dendrometers to establish threshold values for an automatic irrigation schedule method based on soil moisture measurements, as well as evaluation against a number of independent scheduling methods.

Materials and Methods

The experiment was conducted at Mwenezana Estate, located 21.4ºS, 30.62ºE and 515 m above mean sea level in the south-eastern lowveld part of Zimbabwe. The project was a complete randomized design with the following four irrigation scheduling treatments set up in each quadrant under a 50 ha centre pivot with 25 mm irrigation applications: (i) automated Watchdog (based on soil water content), (ii) Class A-pan (control: current grower practice and based on pan evaporation measurements), (iii) Modified Class A-pan (similar to the control, but with updated site-specific pan coefficients) and (iv) irrigation charts (generated by the ZIMsched 2.0 water balance model (Lecler, 2003; Lecler, 2004)). In the automated method, irrigation scheduling was effected by a soil moisture probe (theta probe, type ML2x, Delta T Devices, Cambridge, UK) buried horizontally 30 cm below the soil surface (taken to represent soil moisture depletion in the root zone). Another probe was installed at 60 cm to monitor deep percolation. The two probes were connected to the automatic weather station (Watchdog, Model 900ET, Spectrum Technologies, USA), which was programmed to calculate and store averages of the probe readings every 15 minutes. An electronic alarm circuit with a dry contact control relay that operated as a normally-open single pole switch, was connected to the automatic weather station. The relay was set to close when soil moisture within the root zone depleted to a predetermined threshold. This triggered the alarm circuit, producing sound audible within a range of 1 km. When this happened the pivot was turned on manually and 25 mm of irrigation was applied, enough to recharge the soil moisture in the root zone to field capacity. By doing so, partial automation of the scheduling was achieved. In order to establish the threshold for the automated irrigation scheduling, a separate plot from the main experiment, but with similar soils, was chosen in an area where furrow irrigation was practiced. One half of this plot was under-irrigated to produce appreciable stress. Two dendrometers (Model DEX100, ICT International Pvt Ltd, NSW, Australia), were fastened to the cane stalks to give continuous measurements of variations in diameter in response to water stress. From stem diameter variation measurements, maximum daily shrinkage (MDS), daily evolution (DE) of maximum stem diameter and stem growth rate were derived. MDS was calculated as the difference between maximum and minimum daily stalk diameter and DE was calculated as the difference between maximum stalk diameters on two consecutive days. Soil moisture was simultaneously measured in both plots using time domain reflectometry (TDR) to establish the threshold of irrigation. The threshold was taken to be that soil water content corresponding to when the growth rate (DE) remained unchanged or changed only very slightly and the MDS exceeded a certain prescribed value for two or three consecutive days. In order to assess the response of the crop to different irrigation schedules, stalk heights were measured in the different fields. Measurements were taken according to Triangle guidelines (Anon, 1997) and compared to the ideal figures provided by the Zimbabwe Sugar Association Experiment Station (ZSAES). Ten stations (with three stalks per station) were established in each field for the measurements, which were taken on a weekly basis.

Results and Discussion

Stalk size monitoring

Figure 1 shows the changes in stalk diameter over a two-week period of water stressing. Diurnal oscillations of around 0.1 mm are obvious throughout, while the daily mean diameter increased steadily for the first half of the period and then remained steady. The plants were seen to begin to show signs of stress when the soil depleted to a soil water content of 0.23 m^3/m^{-3} and corresponding to changes in DE of less than 0.006 mm and MDS values exceeding 0.2 mm. Further stressing showed that when water stress developed, the MDS increased and the DE decreased and even became negative under severe water stress.

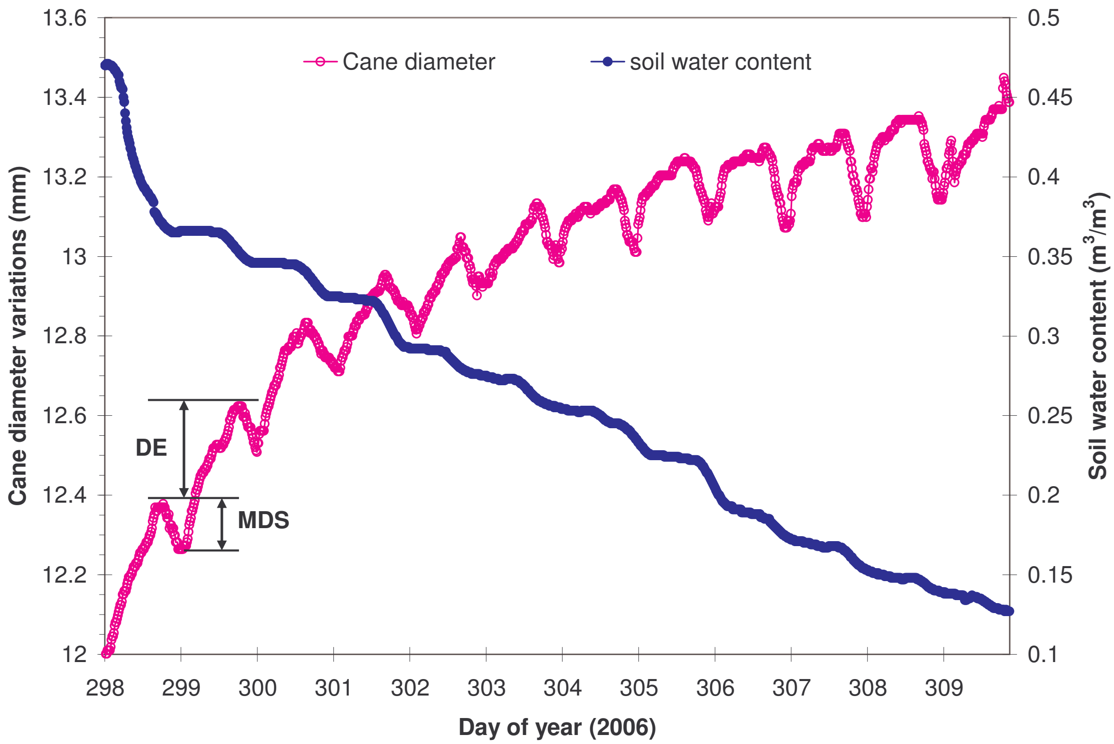

Figure 1. Cane stalk diameter variations in a water-stressed sugarcane plant of variety NCo376 eight months after cutting. The stressing period shown here is from 25 October (DOY 298) to 6 November (DOY 310)

Irrigation

Irrigation events in the automated treatment were successfully done on time, based on the siren that warned when soil water fell below the set threshold of 0.23 m^3/m^{-3}. Irrigation water within the class A-pan and modified class A-pan based treatments was managed within the permissible range, i.e. between total available moisture (TAM) and 50% TAM. Under cloudy conditions from 8 January to 1 February the ZIMsched charts overestimated evapotranspiration and the irrigation events recharged the soil beyond field capacity. The charts therefore proved to be a rigid method of estimating crop evapotranspiration that cannot adjust for shifting climatic conditions. Over the three-month test period, field I4, with automated scheduling used a total of 3.75 ML (9.2%) less water than field I6, irrigated according to the standard procedure relying on the class A-pan. The modified class A-pan (field I5) required 4.375 ML (10.4%) more than the class A-pan, and ZIMsched (field I7) required 9.375 ML (22.4%) more water than the class A-pan.

Growth and yield

There were no significant differences in stalk height gain at the 10% confidence interval, both within and between fields. However, all the treatments recorded less height gain than the ideal. Several factors could have contributed to this, namely differences in plant populations, amount of fertiliser applied, and soil variability within the different fields.

Cane yield of the different irrigation treatments were compared to the long-term means of the respective fields, calculated for the past seven years. The highest yield was obtained in the ZIMsched treatment (field I7), followed by the modified class A-pan method (field I5), the automated method (field I4) and the class A-pan method (field I6). Some of the contributing factors are that the field areas are not exactly equal, and the soils within the different fields are not homogeneous. However, the yields from all the fields surpassed the long-term means.

Conclusions

The experiment started in the middle of the growing season and ended before harvest, therefore the results obtained on yields are not conclusive. However, the automatic scheduling technique, using soil moisture sensors, resulted in the minimum water applied by reducing deep percolation. The automated system provided an alarm signal when irrigation was required; it should be a simple engineering task to develop this to fully automated control.

The assessment of plant stress by measurements on the plant itself remains unproven, for sugarcane. However, stalk diameter fluctuation measurements showed great potential for use as water stress indicators in sugarcane, and hence irrigation control. Future challenges include the up-scaling procedure and the choice of plants to be used for the process. A further trial is recommended, covering the entire growing period of the crop.

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