SUGARCANE IRRIGATION SCHEDULING IN PONGOLA USING PRE-DETERMINED CYCLES

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Abstract

The aim of this study was to develop and evaluate simple to use irrigation scheduling guidelines for Pongola. The guidelines show recommended irrigation cycles for different months of the year, dependent on ratooning/cutting dates and type of irrigation system. The guidelines were developed using the CANESIM computer simulation model and long-term means of daily weather data. They include a simple method to adjust the irrigation cycle whenever it rains. To evaluate the guidelines, the CANESIM model was used to simulate crop yields and water use for crops cut from March to December using daily weather data for the period 1968 to 2001. The simulated crop yields and irrigation water applied, assuming irrigation water applications were scheduled using the cycle guidelines, were compared with the crop yields and irrigation water applied simulated if irrigation scheduling was based on the use of near-real-time daily weather data and the CANESIM computer simulation model. The index of agreement 'd' between the two sets of simulated sugarcane yields was 0.93, a value of 'd' equal to 1.0, indicating perfect agreement. The difference in the means of the two sets of simulated seasonal sugarcane yields was only 2%. The amounts of irrigation water applied were also similar. The increase in profit margins using either the cycle guidelines or the CANESIM model for irrigation scheduling, compared with irrigation scheduling based on simple summer and winter cycles, as are often used in Pongola, ranged from approximately R1079 per hectare to as much as R3485 per hectare when an opportunity cost of water was considered.

Keywords: sugarcane, irrigation scheduling, CANESIM, computer simulation, economics

Introduction

The challenge of producing management tools to aid sugarcane growers with irrigation scheduling has resulted in the development of a number of computer based water budgeting tools such as CANESIM (Singels, *et al.*,1998) and *ZIMsched* (Lecler, 2000). However, many farmers, in particular small scale and emergent farmers, are reluctant to use computer-based irrigation scheduling programs or do not have easy access to such technologies. To provide such farmers with appropriate irrigation scheduling guidelines, Lecler (2003a) proposed using computer simulation models to develop relatively simple to use scheduling charts or calendars. These showed the average number of days between successive irrigation water applications for cane cut at different times during the harvest season, for different types of irrigation systems, on different soils. A robust methodology to determine and account for effective rainfall was also developed for use with the charts. However, the potential benefits of the concepts proposed by Lecler (2003a) were not quantified nor assessed in comparison to more or less sophisticated irrigation scheduling approaches. The aim of the investigation reported here was to develop a similar set of irrigation scheduling guidelines for the Pongola region of South Africa, evaluate these new guidelines by comparison with more and less sophisticated approaches to irrigation scheduling and refine the concepts/guidelines where necessary. The irrigation scheduling guidelines developed show recommended irrigation cycles for different months of the year, dependent on ratooning/cutting dates and type of irrigation system. For this paper the guidelines for centre pivots were evaluated and are discussed.

Methodology

Daily weather data recorded at the Pongola weather station for the period 1968 to 2001 were used in this study. The Pongola weather station is located at latitude 27º 24' south and longitude 31º 35' east. Mean values of maximum and minimum temperatures and sugarcane reference evaporation were determined for each day of the year. This information was then used in the CANESIM (Singels *et al*., 1998) sugarcane crop yield and water budgeting computer simulation model to determine the number of days between successive 25 mm irrigation water applications, assuming no rainfall – called the 'dry cycle'. Dry cycle values were determined for the first and second half of each month of the year, for harvest dates coinciding with the first day of each month in the March to December cutting season. An example of the dry cycle values for a crop cut on 1 March is shown in Table 1, where the irrigation cycle for the first half of May is given as eight days, and for the second half of May, nine days.

Table 1. Recommended irrigation cycle lengths for the first and second half of each month for 25 mm irrigation water applications. The cycles were determined for Pongola using the CANESIM computer simulation model (Singels *et al*., 1998) assuming no rainfall, a March cut crop and no drying-off period.

Month	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Cycle	28/10	10/9	8/9	9/9	8/8	6/5	4/4	3/3	3/3	3/3	3/3	3/3

Accounting for rainfall – the rainfall rule

The rainfall rule is an adaptation of that used by Lecler (2003a). Using the daily mean cane reference evaporation (E_{ref}) values for Pongola, the monthly E_{ref} values were determined as shown in Table 2. To account for effective rainfall, the amount of rain recorded was divided by the respective mean monthly E_{ref}. This result, rounded down to the nearest whole number, was the number of days to be added to the dry cycle associated with a particular month. The number of days that were added per 'rainfall cycle' was limited to a maximum of six. A rainfall cycle was defined as a group of consecutive days on which some rain falls, i.e. a rainfall cycle starts on the first day of rain and ends when there is a day of no rain. For example, if the following amounts of rain were recorded for 10 days: 0 mm, 20 mm, 48 mm, 23 mm, 0 mm, 40 mm, 0 mm, 0 mm, 60 mm and 0 mm, there would be three rainfall cycles, namely, days 2, 3, 4, day 6, and day 9.

Table 2. Mean monthly values of cane reference evaporation (E_{ref}) for Pongola.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
E_{ref} (mm/day)	6.1	5.3	4.4	3.5	2.9	2.6	2.8	3.6	4.5	4.9	5.5	5.9

Using the guidelines

The guidelines show the irrigation cycle length for each month dependent on a particular harvest date, and the rainfall rule is used to account for the effect of rainfall on these pre-determined irrigation cycles. For example, consider a crop cut on 1 March.

Step 1: Within the first week after cutting apply sufficient water to refill the soil profile to the drained upper limit or field capacity.

Step 2: Look up the dry cycle value for the current month, i.e. March initially in this example. This dry cycle value is the number of days between successive irrigation water applications. The next irrigation water application would therefore be planned for 30 March, i.e. the dry cycle value for the first half of March is 28, and there are 28 days between 1 March when the crop was cut and 30 March, the next planned irrigation water application date.

Step 3: If it rains before the next proposed irrigation water application, apply the rainfall rule and delay the proposed irrigation application date for a period equal to the number of days determined using the rainfall rule. Continue this procedure until the proposed irrigation application date is reached. For example, say rain caused a further five days to be added on to the March dry cycle value, this would result in the next application date being delayed until 4 April. An irrigation water application of 25 mm should then be applied on this day. April would now be the current month, therefore lookup the dry cycle value associated with the beginning of April (for a March cut crop), which is given as 10 days in Table 1. The next irrigation application should then take place on 15 April (after counting 10 days) if there is no further rain.

Steps 2 and 3 would be repeated until drying off or harvest. In this investigation it was assumed that irrigation continued until harvest.

Evaluation of the pre-determined irrigation cycle guidelines

Scheduling irrigation water applications using the pre-determined irrigation cycle guidelines and rainfall rule (CY-RR), was compared with scheduling using near-real-time daily weather data and the CANESIM model (C-NRW). In addition, both these scheduling approaches were compared with another two, less sophisticated, irrigation scheduling approaches. To expedite this procedure, a computer program was written to perform the abovementioned CY-RR implementation steps for crops harvested in months March until December of each year from 1968 to 2001. The program determined the dates on which irrigation application amounts of 25 mm would have been applied if the cycle guidelines and rainfall rule had been used in each of these 340 cropping seasons.

Simulated trials for each season were then carried out. First, CANESIM was set to irrigate automatically whenever 25 mm of water had been depleted from the soil profile, with the constraint of a minimum irrigation cycle time of three days, i.e. based on the assumption that to apply 25 mm with a centre pivot would require at least three days. After this CANESIM was set such that irrigation water applications were simulated to take place according to the irrigation dates applicable to the CY-RR scheduling method. As a comparison with what a grower may be doing in practice, a further two methods of scheduling were simulated in CANESIM.

Both methods had fixed irrigation cycles, described as follows:

Method 1: 25 mm of water applied on a 3-day cycle in summer and a 7-day cycle in winter.

Method 2: 25 mm of water applied on a 7-day cycle in summer and a 14-day cycle in winter.

Summer included the months of October through to March, and winter the months April through to September.

The investigation was carried out based on evidence that CANESIM adequately represents the sugarcane growing processes in terms of crop yield and water use (Singels *et al*., 1998; Singels *et al*., 1999; Bezuidenhout and Singels, 2003). Other information used in the simulations is given in Table 3.

Table 3. Information used for the CANESIM simulation trials.

CANESIM variable	Value
Total available moisture (mm)	100
Allowable depletion level (mm)	70
Irrigation refill level (mm)	95
Crop starting year, month, day	As per trial
Crop ending year, month, day	As per trial
Irrigation system	Sprinkler
Initial soil water content (mm)	70
Row spacing (m)	1.5
Ratoon or plant crop	Ratoon

Economic analysis

For the economic analysis, the four different scheduling approaches were compared in terms of Net Returns per Hectare and Relative Net Returns, as defined in Equations 1 and 2 (after Lecler, 2003b).

Net Return per Hectare (NRH) = (Gross Revenue - Yield Dependent Costs - Irrigation Variable Costs - Base Production Costs) / Hectares in production (1)

Relative Net Return (RNR) = Net Return per Hectare x Relative Production Area (2)

Gross revenue is the product of tons RV and the RV price. Yield dependent costs are costs that depend on yield. In this study, the only yield dependent costs assumed to vary with the different irrigation scheduling methods were the costs associated with harvesting and haulage. Irrigation variable costs included in this analysis were the direct costs of water and the electricity used to pump the water. Base production costs, for example, herbicides, labour and seed, were assumed equal for all scheduling scenarios. The relative net return allows for the opportunity cost of water to be accounted for; for example, when water savings could be used to increase the production area, or to increase average production over a number of drought seasons. This is a vital consideration, especially when the availability of water, as opposed to land, limits potential sugar production.

The mean of the simulated crop yields and associated mean of irrigation amounts applied for the four different methods of scheduling were used in the economic analysis. A management factor was used to reduce the simulated cane yields to 80% of their initial values, so that the analysis was more representative of typical conditions in practice rather than research conditions. The cost and revenue assumptions made for the economic analysis are shown in Table 4.

Table 4. Information and costs used for the economic analysis.

Parameter	Value	Units
Water costs	0.1233	R/m^3
Electricity costs	1.15	R/mm.ha
Harvesting and haulage costs	45	R/t
Common base production costs	4000	R/ha
RV price	1250	R/ton

Results and discussion

Yield analysis

A scatter plot of simulated yields is shown in Figure 1. On average, the yields simulated when scheduling according to the pre-determined cycles and rainfall rule (CY-RR) were very close to the yields simulated when scheduling according to the CANESIM model and near-real-time weather data (C-NRW). Quantitative measures of the yield comparison are given in Table 5.

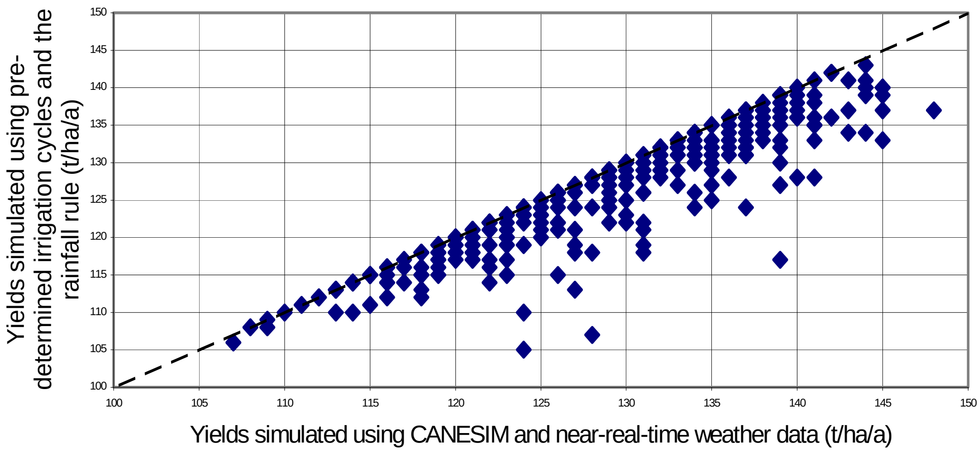

Figure 1. Scatter plot comparison of simulated sugarcane yields.

Table 5. Quantitative measures of a comparison between cane yields simulated using the CANESIM model and near-real-time weather data (C-NRW) to schedule irrigation water applications and cane yields simulated using the pre-determined cycles and rainfall rule (CY-RR) to schedule irrigation water applications.

C-NRW$_{mean}$	CY-RR$_{mean}$	N	a	b	RMSE	d	r
129	126	340	13.323	0.876	4.428	0.930	0.914

Terms N, b, d and r are dimensionless, whereas the other terms are in tons/hectare.

C-NRW$_{mean}$ = mean of simulated yields obtained using the CANESIM model and near-real-time weather data (t/ha)

CY-RR$_{mean}$ = mean of simulated cane yields if irrigation applications were timed using the pre-determined cycles and rainfall rule (t/ha)

N = sample size (number of simulated trials run)

a, b	=	y-intercept and slope respectively, of least squares regression between CY-RR yields as the dependent variable and C-NRW yields as the independent variable
RMSE	=	root mean squared error (CY-RR compared with C-NRW)
d	=	index of agreement where a value of 1.00 would indicate perfect agreement (Wilmott, 1981)
r	=	correlation coefficient (Pearson's r)

The 2% difference in mean simulated crop yields, coupled with the close to unity values of d and r, show that, overall, scheduling using the CY-RR method was very effective when compared with the C-NRW method, even though there were a few years when the yields were substantially lower (cf. Figure 1).

Irrigation amount analysis

A scatter plot of annual amounts of irrigation water applied is shown in Figure 2. Irrigation water applied varied greatly, depending on climate during the cutting season. However, an important result was that the majority of the data points were below the one-is-to-one line, indicating that, on average, scheduling using the CY-RR method used less water than scheduling according to C-NRW. Quantitative measures of amounts of irrigation water applied are given in Table 6.

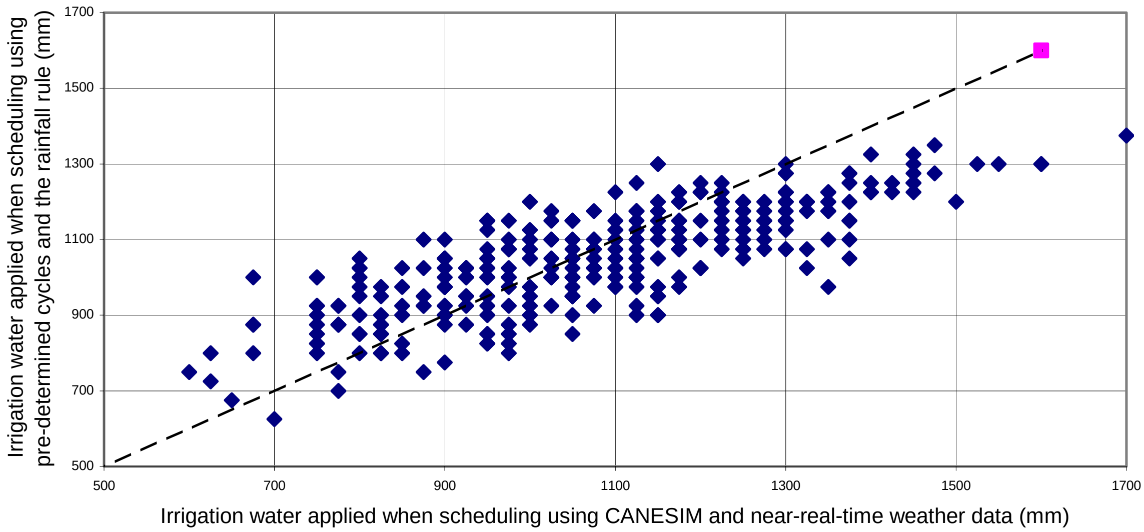

Figure 2. Scatter plot comparison of simulated amounts of irrigation water applied.

Table 6. Quantitative measures of a comparison between annual amounts of irrigation water applied, simulated using the CANESIM model and near-real-time weather data (C-NRW) compared with annual amounts of irrigation water applied simulated if irrigation applications were timed using the pre-determined cycles and rainfall rule (CY-RR).

C-NRW_{mean}	CY-RR_{mean}	N	a	b	RMSE	d	r
1086	1055	340	469.5	0.539	129	0.849	0.800

Terms N, b, d and r are dimensionless, whereas the other terms are in tons/hectare.

$C\text{-}NRW_{mean}$	=	mean of simulated irrigation water applied using the CANESIM model and near-real-time weather data (t/ha)
$CY\text{-}RR_{mean}$	=	mean of simulated irrigation water applied if irrigation applications were timed using the pre-determined cycles and rainfall rule (t/ha)
N	=	sample size (number of simulated trials run)
a, b	=	y-intercept and slope respectively, of least squares regression between CY-RR water applied the dependent variable and CY-NRW water applied as the independent variable.
RMSE	=	root mean squared error (CY-RR compared with C-NRW)
d	=	index of agreement where a value of 1.00 would indicate perfect agreement (Wilmott, 1981)
r	=	correlation coefficient (Pearson's r)

The RMSE value of 129 mm shows that there was about a 11% difference in simulated seasonal irrigation water applications even though the means of all simulated seasons were much closer. On average, the amount of irrigation water applied simulated using CY-RR is less than that simulated using C-NRW. The values of d and r both indicate reasonable agreement and correlation. This is important because, ideally, the CY-RR approach should reflect the influence of a particular season's climate, in particular rainfall, similarly to scheduling with C-NRW. The regression coefficients, a and b and scatter plot shown in Figure 2, show that in low rainfall years when seasonal irrigation amounts are high, the CY-RR method of scheduling results in less water being applied than if scheduling using the C-NRW method, whereas the opposite is true in seasons of high rainfall. Although there were differences in the seasonal amounts of irrigation water applied, in excess of 200 mm, this had a limited detrimental effect, as the difference in means of simulated crop yields over all seasons was only 2%. This indicates that the CY-RR method of scheduling is robust, but not necessarily optimal in all seasons. Further evaluation of the CY-RR approach on soils with lower TAM values, which may not be as 'forgiving', is advised.

Economic comparison

The economic analysis produced the results shown in Table 7. The difference between the NRH, whether scheduling with C-NRW or CY-RR, was negligible. However, the difference between either one of these more scientific scheduling approaches, and what is often typical in practice, represented by Method 1 or Method 2, was substantial, ranging from R1079 per hectare up to R2687 per hectare. The inefficiency of Method 1 meant that it required 21.93 Ml of water per hectare, which was more than double the water required when scheduling using the CY-RR, C-NRW or Method 2. Apart from the high power and water costs, this meant that for every one hectare irrigated using Method 1, the same amount of water could have been used to irrigate more than two hectares using any of the other scheduling methods. Relative overall returns if water limited production could, therefore, be increased by approximately R3485 per hectare irrigated according to Method 1, by increasing the relative production area, for example, during droughts, and scheduling according to C-NRW or CY-RR. While Method 2 used the lowest amount of water and had relatively low power and water costs, the timing of the water applications was not optimal. This was reflected in the low simulated crop yields and relatively lower NRH and RNR compared with scheduling using C-NRW and CY-RR. The mean of the yields simulated using Method 2 for scheduling, was approximately 14% less than the mean of yields simulated using C-NRW, CY-RR or Method 1.

Table 7. Economic comparison of simulated irrigation scheduling scenarios.

	C-NRW	CY-RR	Method 1	Method 2
Mean simulated cane yield (t/ha/a)[a]	103	101	102	89
RV equivalent @ 12% RV (t/ha/a)	12.4	12.1	12.3	10.7
Irrigation water applied (Ml/ha)	10.86	10.55	21.93	9.79
Affected variable costs:				
Water (R/ha)	1304	1266	2631	1175
Power (R/ha)	1249	1213	2522	1126
Harvesting and haulage (R/ha)	4644	4546	4607	4007
Common base production costs (R/ha)	4000	4000	4000	4000
Revenue (R/ha)	15480	15153	15356	13358
(a) Net return per hectare (NRH, R/ha)[b]	4283	4128	1596	3049
(b) Relative water limited production area (ha)	1	1.03	0.50	1.12
(c) Relative net returns = (a) x (b) (RNR, R)	4283	4251	798	3415

C-NRW = irrigation scheduling using the CANESIM model and near-real-time weather data
CY-RR = irrigation scheduling using the pre-determined irrigation cycles and the rainfall rule
Method 1 = 25 mm of irrigation water applied every 3 days in summer and every 7 days in winter
Method 2 = 25 mm of irrigation water applied every 7 days in summer and every 14 days in winter
[a] Simulated yields shown here have been adjusted downwards, assuming an 80% management factor
[b] Net return per hectare and therefore the relative net returns shown here include affected variable costs of water, power and harvesting and haulage and common base production costs, for example, fertiliser, herbicides, seedcane and labour, which were assumed equal to R4000/ha.

Discussion and conclusions

The aim of this investigation was to refine and to evaluate a potentially simple but effective irrigation scheduling approach proposed by Lecler (2003a). In essence, Lecler (2003a) used a computer simulation model to determine average intervals between successive irrigation water applications and a simple rule to account for effective rainfall. In this study, rather than determining the intervals between successive irrigation water applications, the approach was refined to show recommended irrigation cycle times for each month of the year, dependent on a particular harvest date and irrigation application amount. There were instances when the use of the pre-determined irrigation cycles and the rainfall rule resulted in a substantial reduction in simulated crop yields relative to yields simulated using the CANESIM computer simulation model and near-real-time daily weather data for scheduling. Nevertheless, in 340 computer simulation trials, the average reduction in crop yields was only 2%.

In terms of impacts on profitability, there was a negligible difference between using CANESIM and near-real-time weather data for irrigation scheduling and scheduling using the pre-determined cycles and rainfall rule. Importantly, there was a substantial gain in simulated profitability compared with less scientific but typical approaches to irrigation scheduling which have been observed in practice, ranging from R1079 up to R3485 per hectare, if an opportunity cost of water was considered.

The only tools required to use the pre-determined cycles and rainfall rule would be the cycle guidelines themselves, a rainfall gauge and a calendar. This makes this relatively simple method of irrigation scheduling potentially effective not only in terms of water management, but also in terms of costs and appropriateness – a concern for all growers, but especially the small scale growers.

Scheduling irrigation water applications using these pre-determined irrigation cycles and the rainfall rule proved to be robust and effective in this Pongola case study. It could, therefore, represent an appropriate way to utlilise and tailor the output of more complex computer simulation models so that they have wider application and impact.

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