AN EXTENSION PILOT PROJECT TO PROMOTE SUSTAINED IRRIGATION SCHEDULING OF SUGARCANE CROPS BY UMFOLOZI GROWERS

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Abstract

Correct irrigation scheduling adds value and achieves more effective use of limited water resources. During the past decade local grower co-operators demonstrated that flood, sprinkler, centre pivot and drip irrigation systems could produce impressive results using several scheduling methods. However, a method that was sustainable by the average grower remained elusive. Developing appropriate technology for sugarcane irrigators is therefore an ongoing extension challenge. This paper outlines a simple irrigation control method operational on 'Viewlands' farm since April 1996. It is dynamic, easy to use and has been sustained for a number of seasons.

Introduction

While the art of irrigating sugarcane crops is centuries old, applying modern technology to best advantage requires appropriate new skills. However, if that technology is presented to farmers in an unacceptable form, its use will not be sustained and irrigation will continue to be an art rather than a science. From the 1996-97 season onwards, the Viewlands farm project tested a practical irrigation scheduling spreadsheet package that made use of automatic weather station data and a computer driven crop model, to calculate daily crop water use. This project evolved from earlier and largely unsuccessful efforts by South African Sugar Association Experiment Station (SASEX) extensionists and specialists to develop more acceptable ways to schedule irrigation.

Culverwell (1996) indicated the importance of irrigation to the Northern Region and summarised extension efforts to promote more effective use of water since the early 1980s. He showed how irrigation scheduling advice had moved from a clerical, high input, profit and loss method using daily Class A pan and rain gauge readings to a perceived easier minimal input 'pegboard' system developed by George (1988). Neither system has been adopted by growers. Direct measurement of soil moisture was also attempted with help from a co-operator. Gypsum blocks made by SASEX were tested but proved unsatisfactory. A neutron probe was used for a number of years, but recorded data was not used effectively without significant inputs from SASEX advisors. A commercial venture used a neutron probe to advise irrigators when to apply water, but failed due to lack of support. These set-backs motivated a change towards more automated, computer driven scheduling. The CANEGRO crop model developed by Inman-Bamber (1991) used climatic data recorded by automatic weather stations (AWS) to determine daily crop water demands. The system continues to be developed, as recorded by Inman-Bamber *et al.* (1993), McGlinchey *et al.* (1995), McGlinchey and Inman-Bamber (1996), McGlinchey (1997), McGlinchey (1998) and Singels *et al.* (1998).

An initial step at Umfolozi was to use historical local trial results to encourage irrigators to commission two AWS. Using the methodology described by McGlinchey *et al.* (1995), daily water demands (Etp) of a standard three metre tall sugarcane crop (crop factor 1,0) were calculated. This information was available from the extension office to irrigators on demand. Weekly summaries were also transmitted via the local farmers' radio network. AWS stakeholders were given durable, pocket-sized quick reference cards to read off appropriate crop factors for any given age of plant or ratoon cane. Daily evapotranspiration (Et) for any given field could then be calculated easily by multiplying AWS Etp by the appropriate crop factor. The initial plan was that Etp values thus determined would replace long term mean Class A pan data used in the pegboard system described by George (1988), and a significant number of boards were commissioned by growers. Unfortunately this method, like those before, fell into disuse. Extension remained confronted by the challenge of presenting irrigation scheduling technology in a form that clients would continue to use in a situation of low water costs and, on average, sufficient rainfall only to produce a mediocre sugarcane crop. The next approach was to modify and retest the AWS/crop model system with the involvement of a single co-operator on a whole farm basis. Viewlands farm, located on the north bank of the Umfolozi river flood plain, was made available. An irrigation scheduling system that combined the old profit and loss and the new AWS/crop model methods in a manner acceptable to the co-operator was then developed and tested. Appropriate and understandable terminology was also agreed upon. The user's perspective that technology was a means to achieve enhanced productivity and profitability plus conservation of water and pumping energy, was respected by extension with the objective of sustained and effective irrigation scheduling in mind.

Methods and Procedures

The Viewlands pilot project was run for a complete crop harvest to harvest cycle from April 1996 to January 1998. The methods used at the outset are still in practice. Procedures are detailed from an extension/user viewpoint.

All irrigated fields were scheduled with the aid of a simple computer spreadsheet. Minimal routine inputs were required, and included a monthly update of crop factors for each field, a single entry of evapotranspiration potential (Etp) and rainfall data in millimeters into columns common to soil water balance calculations and, lastly, irrigation water (mm) applied to individual fields.

To commence, four main but interacting scheduling principles were explained, discussed, agreed on and implemented. These are indicated below.

- *Exploit plant available water (PAW) in the soil profile to maximise use of rainfall and optimise irrigation*
  Aim: Deplete as much PAW as possible, without causing yield loss. Maintain PAW above freely available level by strategic irrigations planned by means of a simple 'profit and loss' computer spreadsheet.
  Action: Soil profile TAMs (total plant available water between field capacity and permanent wilting point) were determined by SASEX soil surveys and allocated to the 29 irrigation blocks. While it was acceptable to assume that 50% of this TAM was freely available and could be depleted without yield loss, the co-operator chose a more conservative option and only depleted the soil profile by a standard irrigation application before refilling it to field capacity.
- *Provide adequate water to satisfy Et (evapotranspiration) or the crop's effective water demands*
  Aim: Achieve climatic yield potentials by matching Et with just enough irrigation water to supplement effective rainfall.
  Action: Et was determined by applying an appropriate crop factor to the full canopy crop Etp calculated from automatic weather station (AWS) recordings. Initially Etp was provided by the Extension Office but later direct access to the AWS was established. Et was recorded as the 'loss' in the water balance 'profit and loss' spreadsheet calculations.
- *Determine effective water applied to the crop (rainfall plus irrigation)*
  Aim: Calculate effective water applied (profit) by using conservative but realistic efficiencies to allow for water losses.
  Action: 70% efficiency was applied to overhead sprinkler irrigation. Nett irrigation was therefore recorded as 45 and 22 mm per 12-hour and 6-hour stand-time respectively, in accordance with the sprinkler specifications. Actual nett irrigation applied per stand time was checked by measuring water collected in 500 ml cans scattered throughout the wetted area. The assumptions of nett irrigation were proved to be acceptable given the inherent inefficiency of overhead sprinkler irrigation. At field capacity (PAW = TAM) or profile full, no further rainfall or irrigation was credited. At permanent wilting point (PAW = zero) or profile empty, no further Et was deducted. Soil water balances were therefore registered within a crop orientated 'water gauge' that ranged from full to empty.
- *Management*
  Aim: To make irrigation scheduling less onerous without compromising correctness and thereby encourage sustained adoption by growers of otherwise meaningless but

IRRIGATION CONTROL SCHEDULE: VIEWLANDS
MONTH:

Field No:	E1	
Soil Full [TAM]	E2	
Irrigate Now	E3	
Stress Starts [FAM]	E4	
Soil Empty [PWP]	E5	
Irrig mm x hrs	E6	
Crop: Starts + P/R	E7	F7
Crop Factor	E8	

Day	Rain mm	Etp mm	W.Bal/ PAW	PAW mm	Irrig mm	Cumulative mm Rain	Cumulative mm Et
			b/fwd	E12	F12	G12	H12
1	B13	C13	D13	E13	F13	G13	H13
2							
30							
31	B43	C43	D43	E43	F43	G43	H43
	B44	C44	s/totals		F44		
			c/fwd	E43	F45	G43	H43

Cells	Calculatons
D13..43	(E12+(-$C13*E$8)+$B13+F13)
E13..43	@IF(D13<=0,0,@IF(D13>E$2,E$2,D13))
G13..43	(G12+$B13)
H13..43	(H12+$C13*E$8)
B,C,F 44	@sum(B13..B43) etc.
F45	(F12+F44)

Figure 1. A simple computer spreadsheet used to schedule irregation on Viewlands Farm.

potentially profitable technology.

Action: A simple computer spreadsheet designed with the grower was used to drive the irrigation scheduling process (Figure 1). Columns A, B and C were common to all fields. Columns D, E, F, G and H displayed data applicable to field No 1. Field No 2 data was displayed in columns I to M, and so on. Information was brought forward from the previous month and carried forward to the next month.

The layout was designed to minimise inputs after initial settings were complete. These were limited to entering daily rainfall and Etp data from the AWS/crop model programme (see Introduction and McGlinchey *et al.*, 1995) plus updating crop factors once a month in every field. Routine inputs (columns B + C) were single entries common to calculations for all fields on the same row. Other spreadsheet cells are explained briefly below.

- E2, 3, 4 and 5: Soil profile plant available water (PAW) values important for management action. Terminology used was likened to a vehicle fuel gauge. Values were determined by soil surveys or pre-set by management. E2: Soil full: PAW (mm) = TAM = field capacity. E3: Irrigate now: Irrigate when PAW (mm) at this level. E4: Stress starts: Lower PAW values no longer freely available = possible yield loss. Normally 50% of E2. E5: Soil empty: PAW (mm) = zero = permanent wilting point (PWP).
- E7 and F7: Crop start dates. Plant or ratoon. Input needed for SASEX crop factor card.
- E8: Crop factor: Applied to Etp to determine actual crop Et.
- B13: Daily rainfall (preferably on farm).
- C13: Etp: Standard Et (crop factor 1,0) determined by AWS/crop model calculations.
- D13: Water balance: Used to calculate PAW. Upper limit = TAM; lower limit = PWP. (Column can be hidden.)
- E13: Plant available water (mm) on that day.
- F13: Actual nett irrigation (mm) applied.
- G13 and H13: Optional accumulative totals of rainfall and Et.

Results and Discussion

Table 1 summarises productivity and water use efficiencies recorded from 41 fields irrigated in 27 blocks and grouped by crop start month.

Method adoption

In 1999, the Viewlands project automatic weather station / crop model / profit and loss spreadsheet method was still being used to schedule irrigation of a third crop cycle. This tool is considered to be practical, easy to operate and flexible. However experience has shown that it is not infallible and, like all other scheduling methods, the most important input is management.

Seasonal effects

Total rain exceeded total Et on 52% of the irrigated blocks during the crop generation cycles. Soil profiles became saturated and ground water accumulated in some fields. Once field capacity was reached, the scheduling system discounted any additional water on the crop. This may from time to

Table 1. Productivity and water use efficiencies for the Viewlands project.

Annualised results	Crop start month										Average
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	
Tons/ha cut											
Cane	95 7	129 7	138 8	119 6	109 0	104 1	99 1	116 8	107 5	91 0	111 1
Rel sucrose	12 8	15 6	17 7	14 5	13 6	13 0	13 0	13 3	12 5	12 1	13 8
Sucrose	12 5	14 4	17 0	15 3	14 7	13 7	14 5	14 2	11 8	11 0	13 9
Water (mm)											
Et	1 283	1 296	1 341	1 207	1 221	1 274	1 167	1 145	1 131	1 180	1 225
Rain (gross)	919	948	1 027	1 130	1 182	1 294	1 335	1 447	1 472	1 638	1 239
Irrigation (nett)	789	778	554	714	672	429	327	328	465	395	545
% rain used	54	55	77	44	46	65	63	56	45	48	55
Tons/ha/100 mm Et											
Cane	7 5	10 0	10 4	9 9	8 9	8 2	8 5	10 2	9 5	7 7	9 1
Rel sucrose	1 00	1 20	1 32	1 20	1 11	1 02	1 11	1 16	1 11	1 03	1 13
Sucrose	0 97	1 11	1 27	1 27	1 20	1 08	1 24	1 24	1 04	0 93	1 14
Tons/ha/100 mm irrigation											
Cane	12 1	16 7	25 1	16 8	16 2	24 3	30 3	35 6	23 1	23 0	22 3
Rel sucrose	1 62	2 01	3 19	2 03	2 02	3 03	3 98	4 05	2 69	3 06	2 77
Sucrose	1 58	1 85	3 07	2 14	2 19	3 19	4 43	4 33	2 54	2 78	2 81

Actual yields	Crop start month										Average
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	
Tons/ha cut											
Cane	103 5	138 8	136 0	129 1	116 3	112 1	114 2	112 7	107 5	91 0	116 1
Rel sucrose	13 9	16 6	17 3	15 6	14 6	14 0	15 0	12 9	12 5	12 1	14 5
Sucrose	13 7	15 4	16 7	16 5	15 7	14 8	16 6	13 7	11 8	11 0	14 6

time have exacerbated the ground water problem with unnecessary irrigation. It was planned to credit subterranean water in the spreadsheet by reducing crop factors or suspending irrigation when water levels were less than 40 cm below surface. However, dip wells installed to measure water tables often filled with silt and were not always used effectively. The contribution of accumulated subsurface water to crop requirements still needs to be quantified practically and managed to best advantage.

Table 2 shows that, after September, gross rainfall exceeded total Et on 12-month equivalent sugarcane crops, and serves as a reminder that scheduling also indicates when **not** to irrigate.

Crop yields

Total estate production: Table 3 compares total estate relative production achieved during the 1997-98 project season with the previous five year average production (1992-93 to 1996-97), being a benchmark of 100%. The 1998-99 season is also shown because, in contrast with the project year, it was a drier season and average yields in rainfed cane crops were below expectation.

Before irrigation scheduling commenced, Viewlands farm historical production was among the best relative to other Umfolozi sugarcane enterprises. The gains shown in Table 3 relative to own production were therefore meaningful. Seasonal effects do, however, cause production fluctuations. It is meaningful therefore, that since irrigation scheduling commenced, total annual production varied over the past three years (1996-98) by only 400 tons cane, compared with a variation of 4 600 tons cane per annum during the five year period 1992-96.

Tons sucrose/hectare/12 months (t.suc/ha/12m): A project **target** yield of 14 t.suc/ha/12m was set. This target represented a practical 75% of an average 18,4 t.suc/ha/12m yield achieved by 19 local demonstration crops produced by various combinations of scheduling methods (pegboard, neutron probe, AWS/crop model) and irrigation systems (overhead sprinkler, drip, centre pivot) over a five year period (1991-95).

The **actual** average yield achieved from 27 irrigation blocks was 14,5 t.suc/ha or 14,0 t.suc/ha/12m. However, yields ranged from 5,4 to 19,3 t.suc/ha/12m, and the variations are quantified in Table 3.

Possible reasons for the poor yields were low soil potentials, old ratoons, older varieties, waterlogged conditions and seasons with below average sucrose % cane. Appropriate replant and remedial progammes were implemented after harvesting was complete.

Tons cane/hectare (tc/ha) yields: Actual cane yields achieved were assessed against calculated climatic potential yields. Thompson and Harding (1986) quantified a relationship between potential sugarcane yields and Et. Their equation: tons cane/ha = $9{,}69\,(^{mm\,Et}/_{100}) - 2{,}4$ ($r=0{,}95$), was applied to total mm Et values recorded for all 27 irrigation blocks. The resultant potential cane yields and the actual cane yields were grouped by crop start month and averaged.

In Table 5, the relationship between actual cane yields (A)

Table 2. Total rain on 12-month old crops as a percentage of total evapotranspiration (Et) by 1996 crop start month.

Start month	Apr-Jun	Jul-Sep	Oct-Nov	Dec-Jan
Rain % Et	72-76	94-102	114-126	130-139

Table 3. 1997-98 and 1998-9 total Viewlands production relative to a benchmark 5-year (1992-93 to 1996-97) average production.

Total Production	5-year avg	1997-98	1998-99
Hectares harvested	100%	96 3%	102 8%
Tons cane	100%	111 7%	109 5%
Tons sucrose	100%	106 4%	110 9%

Table 4. Range of tons sucrose/ha/12 months yields achieved in 27 irrigation blocks on Viewlands farm during scheduling project.

Tons suc/ha/12 mths	>18	>16-18	>14-16	>12-14	>10-12	<10
No of blocks	2	4	8	9	3	1
Cumulative %	7%	22%	52%	85%	96%	100%

Table 5. Comparison of Viewlands 1997/98 actual tons cane/ha yields against cane yield potentials calculated by the Thompson and Harding (1986) formula using actual Et values (A = actual tons cane/ha C = calculated tones cane/ha Fa = actual/calculated yield R = Fa range x irrigated block x crop start month).

	Crop start month										Average month
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	
A	104	139	136	129	116	112	114	113	107	93	116
C	132	132	124	124	124	131	128	105	107	115	122
Fa	0 79	1 05	1 10	1 04	0 94	0 86	0 89	1 08	1 00	0 81	0 95
R	0 77 to 0 80	0 95 to 1 16	0 93 to 1 29	1 00 to 1 08	0 93 to 0 95	0 80 to 0 92	0 89 to 0 90	0 93 to 1 21			0 77 to 1 21

and calculated potential cane yields (C) are shown as a factor (Fa), 1,00 Fa = identical yields. The range of yield factors in any one month (R) indicates the differences in individual irrigation block yield performances. A mathematical average of all start months was also calculated (Average Month) and the extreme range of factors shown (0,77-1,21).

In Table 5, on average, actual yields achieved from April to January (116 tc/ha) approximated (Fa=0,95) to the potential yields (122 tc/ha). If the months of April and January are excluded the actual (120,8 tc/ha) and potential (121,9 tc/ha) yield averages are closer (Fa=0,99). It was acknowledged, however, that actual and potential yields differed in some instances and there was a need to investigate whether below average yields could be improved. The cost effectiveness of attempting to achieve further increases in productivity in all instances compared with reducing input costs will need careful ongoing assessment.

Water use efficiency

Units of measurement: Assessing efficiency of water use was not straightforward. Results given in Tables 1 and 6 include units of measurement often used that have inherent limitations. These were:

- *Tons/ha/100 mm irrigation.* Efficiency of water use measured as tons/ha/100 mm irrigation generally increased as rainfall on the crop increased and irrigation (mm) applied consequently decreased. There was a significant increase in rainfall on late season compared with early season crops. A consequence was that, although averaged efficiencies were 22,3 tons cane and 2,81 tons sucrose/ha/100 mm irrigation applied, results varied by up to 280% between crop start months. The value of this measurement to assess water use efficiency was therefore limited.
- *Percent of total rainfall used by the crop (% rain used).* This was quantified as: % rain used = total Et mm – total nett irrigation mm / total rain mm x 100. The average rain used for all crop start months was 55%, but ranged from 44 to 77% between months. Good rains just after irrigation often reduced % rain used in the 1996-97 season. This measurement was considered a guide to indicate a possible irrigation scheduling problem. It was therefore decided to further test the results from Viewlands against a different standard.

Measuring achievement against a standard: McGlinchey (1998) referred to problems with the measurements outlined opposite, and showed that using different crop models and irrigation scheduling combinations could result in variable irrigation water use efficiencies. It was decided therefore to assess the actual performance for Viewlands (scenario 1) against two simulated scenarios (2 and 3) that used the latest SASEX irrigation scheduling tool, the IRRICANE model described by Singels *et al.* (1998). Similarities and differences in strategies and assumptions used in each scenario are given in Table 6.

Table 7 (overleaf) compares results achieved by the three scenarios. and shows that, despite being a first effort, results achieved by the Viewlands (scenario 1) soil water balance spreadsheet were comparable with simulations carried out by SASEX specialists using the IRRICANE scheduling program (scenarios 2 and 3). Key measurements are compared in the three scenarios.

- *Et mm:* The mean of results for all TAMs (scenarios 2 and 3) did not differ significantly when PAW depletion strategy was changed. Except for April, scenario 1 values were similar to the other scenarios and indicated that the crop factor card was a useful tool.
- *Rain mm:* Differences between on-farm and AWS rainfall highlighted the need to use on-farm records where possible.
- *Irrigation mm:* Except for December, scenario 1 applied more water than the scenario 2 equivalent. However, less rain was recorded and only in August did extra irrigation

Table 6. Similarities and differences in strategies and assumptions used in scenarios 1, 2 and 3 in the Viewlands project.

	Strategy / assumption			Scenario		
				1	2	3
1	TAM options at 70 100 120 mm			X	X	X
2	Same April August December start date			X	X	X
3	Rainfall	a) on farm		X		
		b) from AWS 15 km away			X	X
4	Netting irrigation at 45 mm/12 h or 22 mm/6 h			X	X	
5	Irrigation frequency 8 days minimum			X	X	X
6	Same PAW mm on start date			X	X	X
7	Etp mm (mature crop) daily from AWS			X	X	X
8	Et mm	a) crop factor card x etp used		X		
		b) calculated by IRRICANE program			X	X
9	PAW at field capacity depleted before irrigation					
		a) by nett irrigation (mm) per stand time		X	X	
		b) by 50% TAM mm				X
10	Results	a) 365 days from crop start date			X	X
		b) annualised if crop not 12 months old		X		
11	Irrigation schedule		a) Viewlands spreadsheet	X		
			b) IRRICANE program		X	X
12	Actual situations and challenges			X		

Table 7. Comparison of Viewlands spreadsheet water balance scheduling results (Scenario 1) with results from simulated irrigation scheduling using the SASEX IRRICANE programme (Scenarios 2 and 3).

TAM	Crop start	Mid-April 96			August 96			Mid-December 96		
(mm)	Scenario	1	2	3	1	2	3	1	2	3
All	Et mm	1 283	1 384	1 349	1 221	1 241	1 225	1 180	1 256	1 250
All	Rain mm	919	1 308	1 308	1 182	1 302	1 302	1 568	1 606	1 606
70	Irrigation mm	859	833	720		585	518	520	585	473
100		719	675	630	678	450	450	354	450	405
120			675	585	655	450	450		450	360
70	T cane/ha/100 mm irrigation	13	17	20		23	25	19	22	27
100		13	21	22	16	29	29	33	29	32
120			22	24	18	30	30		29	36
70	% rain used	46	43	48		50	54	42	42	48
100		61	55	55	46	61	60	53	50	53
120			55	58	48	61	60		50	55

exceed rainfall differences. Scenario 3 generally demonstrated the advantages of depleting the PAW by 50% of TAM below field capacity, and less irrigation was needed with increasing TAM – except for August.

- *Tons cane/ha/100 mm irrigation:* In most instances scenario 1 results indicated there was potential to improve actual performance against a target ideal. The differences in simulated yield potentials between scenarios 2 and 3 did not exceed 2 tons cane/ha.
- *Percent rain used:* Scenario 1 performed well compared with the other scenarios, except in August.

The comparison of an actual whole farm performance with simulated options was useful in assessing both actual and the model programs. The Viewlands project not only achieved satisfactory results but also provided detailed records in a form that could easily be compared with a standard and used to correct shortcomings.

Conclusion

There are very significant potential benefits when sugarcane growers schedule irrigation water correctly. The Viewlands project proved that it is a scheduling system that could be acceptable to sugarcane irrigators. The method continues to be sustained by the co-operator into the third season. Total tons cane and sucrose produced during the project year exceeded the production for the past five year mean, while further upward trends continued into the following season. Average cane yields from 25 irrigation blocks were close to the climatic potentials calculated by an acceptable method. However, two low yielding blocks reduced the overall performance. Water use efficiencies were difficult to evaluate because relevant standards and historical performances were not available. Although there was potential to improve efficiencies and reduce the amount of water used for irrigation when compared with the sophisticated IRRICANE programme, actual performances were acceptable. Overall there was a feeling of achievement and an acknowledgement of lessons learnt. Changes were implemented and the challenge is now to improve performance and share the method with other interested irrigators.

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REFERENCES

Culverwell, TL (1996). An ongoing project to promote more effective use of irrigation water on sugarcane crops. *Conf S Afr Soc Agric Ext* 30: 115-118.

George, BRF (1988). A simple method of scheduling irrigation. *Proc S Afr Sug Technol Ass* 62: 149-151.

Inman-Bamber, NG (1991). A growth model for sugarcane based on a simple carbon balance and the CERES-maize water balance. *S Afr J Plant Soil* 8: 93-99.

Inman-Bamber, NG, Culverwell, TL and McGlinchey, MG (1993). Predicting yield responses to irrigation of sugarcane from a growth model and field records. *Proc S Afr Sug Technol Ass* 67: 66-72.

McGlinchey, MG (1997). Irrigation scheduling developments in the sugar industry. *Proc SABI 2001 Congress.*

McGlinchey, MG (1998). Components of the water balance of an irrigated sugar cane crop in Swaziland. *Proc S Afr Sug Technol Ass* 72: 114-116.

McGlinchey, MG and Inman-Bamber, NG (1996). Effect of irrigation scheduling on water use efficiency and yield. *Proc S Afr Sug Technol Ass* 70: 55-56.

McGlinchey, MG, Inman-Bamber, NG, Culverwell, TL and Els, M (1995). An irrigation scheduling model based on a crop model and an automatic weather station. *Proc S Afr Sug Technol Ass* 69: 69-73.

Singels, A, Kennedy, AJ and Bezuidenhout, CN (1998). IRRICANE: A simple computerised scheduling method for sugarcane. *Proc S Afr Sug Technol Ass* 72: 117-122.

Thompson, GD and Harding, RL (1986). A computerised model for evaluating irrigation schemes for sugarcane. *Proc S Afr Sug Technol Ass* 66: 177-182.