

A COMPUTERIZED MODEL FOR EVALUATING IRRIGATION SCHEMES FOR SUGARCANE

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Abstract

A computerized model has been prepared to enable estimates to be made of sugarcane yields when a given amount of irrigation water is used. The input data comprise daily rainfall records for as long a period as possible, average monthly class A pan evaporation figures, and a proposed sequence of planting and harvesting of the crops which comprise a full crop cycle. The monthly increase in green leaf canopy also needs to be estimated. The programme permits the variation of parameters such as total available soil moisture, irrigation efficiency, application rate and an evapotranspiration model. It indicates, for each year and on average, the rainfall efficiency, the number of days spent irrigating, and the number of days during which the crop was subjected to various degrees of stress.

Introduction

If healthy seedcane is planted in a well-prepared seedbed, adequate amounts of fertilizer are used, the crop is kept free of weeds, and pests and diseases do not restrict production, then the yield of a sugarcane crop will depend mainly on the amount of water available. When the amount and distribution of rainfall are satisfactory, sugarcane can be produced profitably without any supplementary water. In many instances, however, there is the prospect that additional amounts of water provided by means of irrigation may be economically warranted, and in some cases the production of sugarcane can only be contemplated if irrigation is possible.

To assess the area of land under sugarcane which should be served by a known supply of water, field experiments may be conducted. Trials in which the water treatments are based on pan factors (eg Gosnell and Lonsdale³) are useful for establishing irrigation control procedures, but to evaluate scheme designs the concept of water duties is more useful. A water duty is conventionally defined as the area to be irrigated using one cumec of water pumped or available at the source (Thompson and de Robillard¹⁰). The treatments in an experiment can be made to represent different water duties according to the following principles:

- (i) assume a predicted irrigation efficiency, eg 85 %
- (ii) establish the amount of water to be applied per irrigation cycle, eg 60 mm
- (iii) apply a measured amount of 51 mm (85% of 60 mm) to each irrigated plot at a prescribed maximum frequency, eg once every 21 days, if the soil moisture deficit is 51 mm or more.

A gross amount of 60 mm every 21 days translates into a water duty of 3024 ha/cumec:

$$60 \text{ mm on } 1 \text{ ha} = 600 \text{ m}^3$$

$$1 \text{ cumec for } 21 \text{ days} = 1814400 \text{ m}^3$$

$$1814400 \div 600 = 3024 \text{ ha/cumec}$$

Similarly, other water duties can be represented by irrigation being available at other frequencies, eg 7, 14 or 28 days. The

operation of an experiment based on water duties is conducted by maintaining a soil moisture profit and loss account for each treatment, and irrigating at the permissible frequency only if the soil moisture deficit is equal to or exceeds the net amount of water to be applied (eg 51 mm). If the deficit is too small, irrigation is delayed until the deficit reaches the required level. The daily moisture status of the profile is assessed from actual rainfall and from local data for class A pan evaporation, which has been related to evapotranspiration of sugarcane in a number of countries (Ekern¹, Fogliata², Hardy⁴, Kingston and Ham⁵, Thompson⁸).

When a water duty experiment has been conducted for a plant crop and a number of ratoons, it provides information that is valid for a single site and for the pattern of rainfall that occurred whilst the trial was in progress. If a satisfactory relationship can be established between total evapotranspiration and crop yield, the potential exists for irrigation experiments to be simulated in a computerized model, allowing each water duty to be equivalent of a treatment in a conventional field experiment. By making use of long term daily rainfall records, the model will have the advantage of representing many more years of climatic variability than a field experiment would ever be likely to cover and the results will become available immediately.

Thus, with long term daily rainfall records and estimates of evapotranspiration, the performance of sugarcane crops under a range of conditions and circumstances can be evaluated, eg various values can be used for the total available moisture content of the soil (TAM), for the amount of water applied per cycle, and for the estimated efficiency of irrigation. In this exercise, the relationship between evapotranspiration (E_t) and crop yield, developed by Thompson⁸ from published data from Australia, Hawaii, Mauritius and South Africa, has been used. The linear relationship between E_t and tons cane per hectare, and the curvilinear relationship between E_t and tons sucrose per hectare, are reproduced in Figure 1. Although the relationship for tons cane was based on 91 sets of data, and that for tons sucrose on 85 sets, the equations would not necessarily be applicable under all circumstances.

Materials and Methods

A computer model was constructed to simulate the irrigation of a set of sugarcane fields, using a soil moisture profit and loss account (Thompson⁹). The required input data consisted of:

- (i) daily rainfall for the period to be simulated
- (ii) average monthly class A pan evaporation figures, accounting for various stages of crop canopy
- (iii) a proposed crop cycle model, including estimates of the degree of crop canopy in each field in each month.

The crop cycle model used in the computer gave the standard sequence of events for a full crop cycle from the time of planting until the end of a fallow period following ploughing out. The only constraints were that the last month of

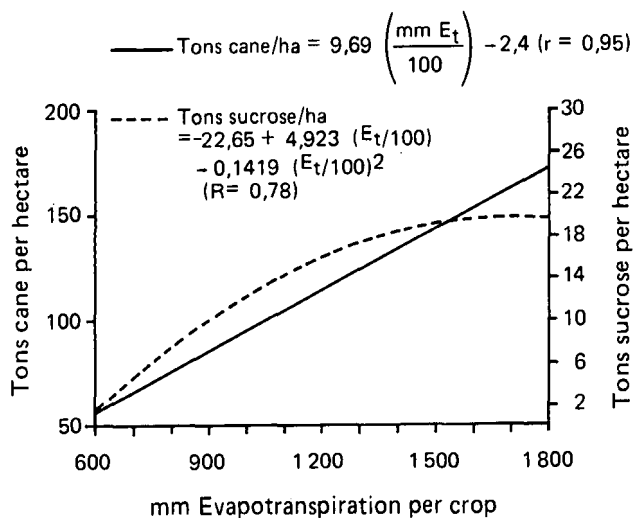


FIGURE 1 Relationships between sugarcane yields and evapotranspiration

fallow should be the month before planting was done, thus making the full crop cycle an exact number of years, and that harvesting of the plant crop or a ratoon crop should occur once in each month of the normal milling season. The monthly increases in green leaf canopy were then superimposed on the crop cycle model and the crop cycle table then gave the crop and canopy stages for each month for the full duration of the crop cycle.

In the computer model there was always a field at each of the yearly stages of the crop cycle. There were thus 9 fields in a 9-year crop cycle and each of the years in the crop cycle table also represented a field which had reached the *n*th year in its cropping cycle. Furthermore, as the computer programme was designed to attempt to irrigate one field each day, the number of days in an irrigation cycle also had to equal the number of fields. Thus an 18-day irrigation cycle would consist of 18 fields, ie two 9-year crop cycles.

Variable parameters in the computer model included:

- (i) the net amount of water to be applied per irrigation cycle
- (ii) the soil TAM content
- (iii) initial soil profile moisture content
- (iv) the length of an irrigation cycle
- (v) the evapotranspiration model to be used
- (vi) the percentage of an application of irrigation water which would have to be accommodated in the soil profile before an irrigation could be scheduled.

The computer printout provided data for each year, and a summary for all of the years under consideration, under various headings, included the following:

- (i) percent rainfall efficiency. When the amount of rain on any one day exceeded the soil moisture deficit for each field in the profit and loss accounts, the excess was classified as 'inefficient' rainfall, not available to the crop
- (ii) mm evapotranspiration. This represented the cumulated *E_t*, which could be converted to yields of cane and sucrose by means of the relationships given in Figure 1.
- (iii) days irrigating. The number of days on which irrigation was required in each year and on average represented a measure of the field labour requirements for irrigation

- (iv) days at wilting point. When the TAM in any field was exhausted and it was not possible to irrigate immediately, the crop was assumed to be at wilting point until rain fell or irrigation was applied.

Daily rainfall records for Big Bend in Swaziland (26°C 51'S, 31° 55'E) and for Mount Edgecombe (29° 42'S, 31° 02'E) were used in the computer exercises. For Big Bend 17 years of continuous reliable data were available (1967/68 – 1983/84 inclusive) and some runs were repeated using 50 years of interrupted data (1923/24 – 1983/84, excluding 1935/36, 1947/48, 1948/49, 1949/50, 1950/51, 1951/52, 1957/58, 1958/59, 1959/60, 1960/61). For Mount Edgecombe, 50 years of continuous records from 1933/34 until 1984/85 were used. Mean annual rainfall for Big Bend was 624 mm (17 year average) or 558 mm (50 year average). For Mount Edgecombe the average was 950 mm.

The computer programme was run starting with an empty profile in each field on 1 May of year 1 with one field at each of the "n" years in the crop cycle. The soil moisture profit and loss account was conducted for each field, taking cognizance of the following:

- (i) daily rainfall for successive years of data
- (ii) the need for irrigation whenever the soil moisture deficit was greater than one efficient application of irrigation water
- (iii) the principle that, when more than one field required irrigation, the one with the greater deficit would be irrigated first
- (iv) evapotranspiration per day, based on class A pan evaporation and the crop cycle model.

The crop cycle model for Big Bend is shown in Table 1, where it can be seen that the plant crop was started in September and was harvested in December of the following year. Succeeding ratoons were harvested one month earlier until the eighth ratoon was harvested in April. This was followed by four months of fallow before re-planting in September after nine complete years. For crops harvested in autumn and winter (April – July), irrigation was suspended for 2 months, but during spring and summer only one month without irrigation was programmed. The milling season was assumed to last for 9 months from April through December.

Table 1
Sequence of events and degrees of canopy over a 9-year period at Big Bend

Year no.	1 and 10	2	3	4	5	6	7	8	9
Month									
January	4	4	1R1	4	4	4	4	4	4
February	4	4	2	4	4	4	4	4	4
March	5	4	4	4	4	4	4	4	4
April	6	4	4	4	4	4	4	4	5
May	7	4	4	4	4	4	4	5	6
June	7	4	4	4	4	4	5	6	8R0
July	7	4	4	4	4	4	6	7R0	1
August	7	4	4	4	4	6	6R0	1	1
September	P0	4	4	4	6	5R1	1	2	2
October	1	4	4	6	4R1	2	2	2	3
November	2	4	6	3R1	2	2	3	3	4
December	3	6	2R1	2	3	3	4	4	4

Codes:

- 0 = bare soil, no canopy
- 1 = ¼ canopy
- 2 = ½ canopy
- 3 = ¾ canopy
- 4 = full canopy
- 5 = drying off, no irrigation
- 6 = harvesting, no irrigation
- 7 = fallow

The estimates of evapotranspiration for each month and each degree of canopy are given in Table 2.

Table 2

Estimates of evapotranspiration at Big Bend based on mean monthly class A pan evaporation, 1967 to 1983

Month	Evapotranspiration, mm/day				
	No Canopy	¼ Canopy	½ Canopy	¾ Canopy	Full Canopy
January	3,0	4,1	5,2	6,4	7,5
February	2,9	4,0	5,0	6,1	7,2
March	2,5	3,5	4,4	5,4	6,3
April	2,0	2,7	3,4	4,2	4,9
May	1,5	2,1	2,7	3,2	3,8
June	1,3	1,8	2,2	2,7	3,2
July	1,4	2,0	2,5	3,1	3,6
August	2,0	2,7	3,4	4,2	4,9
September	2,4	3,4	4,3	5,2	6,1
October	2,6	3,6	4,6	5,6	6,6
November	2,8	3,8	4,8	5,9	6,9
December	3,1	4,2	5,4	6,5	7,7

The situations studied with the Big Bend rainfall data were:

- (i) the effects of changing water duties when the TAM was 110 mm and a total of 60 mm was applied per cycle at

an efficiency of 85 %, ie 51 mm net. The results for a water duty of 3024 ha/cumec were compared when 17 years and 50 years of rainfall data were used

- (ii) the effects of changing TAM between 60 mm and 110 mm with a water duty of 3024 ha/cumec and when a total of 60 mm was applied per cycle at an efficiency of 85 %

- (iii) the effects of changing the irrigation efficiency between 60 and 85 % with a water duty of 3024 ha/cumec and when a total of 60 mm was applied per cycle.

The crop cycle model for Mount Edgecombe is given in Table 3. A plant crop and 7 ratoons were proposed over an 11-year period, and the harvesting season lasted from May to December inclusive. In the northern parts of the sugar industry in southern Africa the crops are invariably burnt before harvesting, but in the cooler climate in the south, either burning or trashing may be practiced. The option of having a bare soil or a trash mulch was therefore introduced into this programme.

The estimates of evapotranspiration at Mount Edgecombe are given in Table 4, being different for bare soil and a trash mulch during the period of incomplete canopy (Thompson?).

Table 3

Sequence of events and degrees of canopy, with bare soil or a trash mulch, over a 12-year period at Mount Edgecombe

Year	1 and 12	2	3	4	5	6	7	8	9	10	11
Month											
January	4	3	1RT0	4	4	4	1	4	4	3	2
February	4	4	1	4	4	4	2	4	4	4	3
March	4	4	2	4	4	4	3	4	4	4	4
April	5	4	3	5	4	4	4	4	4	4	4
May	5	4	4	6	4	4	4	5	4	4	4
June	6	4	4	2RT0	5	4	4	5	4	4	4
July	7	4	4	1	5	4	4	6	5	4	4
August	7	4	4	1	6	4	4	5RT0	5	5	4
September	7	4	4	2	3RT0	4	4	1	6	5	4
October	PB0	4	4	3	1	5	4	2	6RT0	6	4
November	1	5	4	4	2	6	4	3	1	7RT0	4
December	2	6	4	4	3	4RT0	4	4	2	1	4

Codes: as in Table 1 plus
 B = bare soil or crop burnt
 T = trash mulch

Table 4

Estimates of evapotranspiration at Mount Edgecombe based on mean monthly class A pan evaporation, 1966 to 1984

Month	Evapotranspiration, mm/day								
	Bare soil				Trash mulch				Full Canopy
	No Canopy	¼ Canopy	½ Canopy	¾ Canopy	No Canopy	¼ Canopy	½ Canopy	¾ Canopy	
January	2,38	3,27	4,16	5,05	0,89	2,08	3,56	4,75	5,94
February	2,28	3,14	3,99	4,84	0,86	2,00	3,42	4,56	5,70
March	1,96	2,70	3,43	4,16	0,74	1,72	2,94	3,92	4,90
April	1,55	2,13	2,71	3,29	0,58	1,35	2,32	3,10	3,87
May	1,21	1,67	2,12	2,58	0,45	1,06	1,82	2,42	3,03
June	1,08	1,48	1,89	2,30	0,40	0,94	1,62	2,16	2,70
July	1,11	1,52	1,94	2,35	0,42	0,97	1,66	2,22	2,77
August	1,30	1,79	2,28	2,77	0,49	1,14	1,96	2,61	3,26
September	1,60	2,20	2,80	3,40	0,60	1,40	2,40	3,20	4,00
October	1,95	2,68	3,41	4,14	0,73	1,70	2,92	3,90	4,87
November	2,13	2,93	3,73	4,53	0,80	1,86	3,20	4,26	5,33
December	2,40	3,30	4,20	5,10	0,90	2,10	3,60	4,80	6,00

Two separate evapotranspiration models were tested with the Mount Edgecombe data:

- (i) as in the Big Bend programme, TAM was assumed to be equally available to the plant between the limits of field capacity and wilting point
- (ii) TAM was divided into 3 categories (Thompson⁹). The first 50% was regarded to be freely available ($E_t = E_o$). The following 30% was used at a rate of $E_t = 0,5 E_o$, and the final 20% at a rate of $E_t = 0,2 E_o$.

The situations studied with each of the above models using the Mount Edgecombe rainfall data were the effects of water duties of 1584, 3168 and 4752 ha/cumec, compared with rainfed conditions when the TAM was 50, 75 or 100 mm, and when 60 mm of irrigation water was used at an efficiency of 85%. In all the simulation runs conducted with Mount Edgecombe rainfall data the soil profile moisture was set at 50% TAM at the start of the run.

Results and Discussion

When a total of 60 mm was applied per cycle at Big Bend on a soil having a TAM of 110 mm, the results shown in Table 5 were obtained for water duties that varied from 1300 to 3900 ha/cumec. As the water duty increased, the rainfall efficiency increased, the number of stress days per year increased and the number of days irrigating per year increased. These increases were associated with the decreasing yields shown in the table, there being almost a 30% reduction in yield when the water duty was trebled from 1300 to 3900 ha/cumec. Production per cumec of available water, however, increased by more than 100%.

Table 5

Results when water duty was varied at Big Bend (TAM = 110 mm, 60 mm applied per cycle at 85% efficiency)

Cycle time, days	Water duty, ha/cumec	Rain effic %	No. of stress days/year	Days irrigating /year	Est yield		Tons per cumec
					Tons cane/ha	Tons suc/ha	
9	1300	81	31	218	166	20,1	26 130
15	2160	89	53	309	153	19,8	42 770
18	2600	91	69	335	145	19,4	50 440
21	3024	93	89	347	135	18,7	56 550
21*	3024	94	96	352	131	18,2	55 040
27	3900	94	126	354	119	16,7	65 130

* 50 years' rainfall data used.
Remainder all with 17 years' data.

The effect of using 50 years instead of 17 years of rainfall data was also to reduce yields, but only by about 3%, and this was predictable in view of the lower average rainfall for the longer period.

The results given in Table 6 show that, by increasing the TAM from 60 to 110 mm, yield was increased by 10% from 17,0 to 18,7 tons sucrose per hectare, and that it was necessary to irrigate almost continuously throughout the year (347 days) when the TAM was 110 mm.

Table 6

Results when TAM was varied at Big Bend (water duty = 3024 ha/cumec, 60 mm applied per cycle at 85% efficiency)

TAM mm	Rain effic%	No. of stress days/year	Days irrigating / year	Est yield	
				Tons cane/ha	Tons suc/ha
60	84	119	307	121	17,0
80	89	101	331	129	18,0
90	90	96	338	132	18,3
110	93	89	347	135	18,7

In South Africa, overhead spray irrigation on sugarcane lands is estimated to be between 75% and 85% efficient. The best performance with surface irrigation seldom reaches 60% efficiency. In Table 7 it can be seen that yields were reduced by about 15% when irrigation efficiency fell from 85% to 60%. Rainfall efficiency and the number of days irrigating per year were not greatly affected, but the number of stress days was about 80% greater with surface compared with overhead spray irrigation at an efficiency of 85%.

The results obtained using the Mount Edgecombe data are given in Table 8. When the principle of unequal availability of TAM was applied using evapotranspiration model no. 2, exhaustion of the available moisture did not occur, and when the TAM was 50 mm, irrigation was never scheduled. Data are therefore shown for TAM's of 75 and 100 mm only for this model.

The reduction in yield due to employing the principle of unequal availability of soil moisture under rainfed conditions was about 1 ton sucrose per hectare with all three TAM's studied, although the yields were more than 30% lower at a TAM of 50 mm compared with those at a TAM of 100 mm. The results for rainfed conditions confirm that irrigation is not essential at Mount Edgecombe.

With irrigation the yields of sucrose per hectare on soils with a TAM of 75 mm were approximately double those of comparable rainfed yields. Rainfall efficiency decreased by less than 10% due to irrigation in these circumstances.

When sugarcane can be produced under rainfed conditions, but where a limited amount of water may be available for irrigation, as is often the case in Natal, the economics of a proposed scheme must take both rainfed and irrigated yields into account. For instance, consider a 500 ha area at Mount Edgecombe having a TAM of 75 mm, for which 0,1

Table 7

Results when irrigation efficiencies of 60, 75 and 85% were compared at Big Bend (TAM = 110 mm, water duty = 3024 ha/cumec, 60 mm gross applied per cycle)

Irrigation Effic %	Effective amt/cycle, mm	Rainfall effic %	No. of stress days/year	Days irrigating / year	Est yield	
					Tons cane/ha	Tons suc/ha
60	36	94	138	358	114	16,0
75	45	93	106	354	127	17,8
85	51	93	89	347	135	18,7

Table 8
Results obtained using two evapotranspiration models at Mount Edgecombe under rainfed conditions and when the water duty was 1584, 3168 or 4752 ha/cumec (60 mm applied per cycle at an efficiency of 85%)

Cycle time (days) Water duty (ha/cumec)	TAM mm	E _t model No.	Rain effic %	No. of stress days/year	Days irrigating /year	Est yield	
						Tons cane/ha	Tons suc/ha
(Rainfed)	50	1	77	175	-	68	5,7
		2	73	0	-	65	4,7
	75	1	83	158	-	74	7,3
		2	79	0	-	70	6,2
	100	1	87	148	-	78	8,3
		2	82	0	-	74	7,2
11	50	1	68	48	121	113	15,9
	1584	1	70	27	128	118	16,7
		2	71	0	87	102	13,8
	100	1	70	20	131	120	16,9
		2	69	0	126	117	16,5
22	50	1	70	74	189	104	14,2
	3168	1	74	39	222	115	16,1
		2	73	0	147	97	12,9
	100	1	76	27	229	118	16,6
		2	73	0	212	111	15,6
33	50	1	72	97	215	95	12,6
	4752	1	77	58	271	108	15,1
		2	74	0	184	93	12,0
	100	1	80	42	285	113	15,9
		2	75	0	256	103	14,4

cumec of water is available. The comparable amounts of production in terms of total tons sucrose per annum, are as follows:

	Ts/annum
Rainfed: (500 ha × 6,2)	= 3100
1584 ha/cumec:	
(158,4 ha × 13,8) + (341,6 ha × 6,2)	= 4304
3168 ha/cumec:	
(316,8 ha × 12,9) + (183,2 ha × 6,2)	= 5223
4752 ha/cumec:	
(475,2 ha × 12,0) + (24,8 ha × 6,2)	= 5856

The maximum production is attained with the highest water duty, but an economic assessment taking the costs of distributing the irrigation water and running each scheme still has to be carried out.

A further advantage that accrues from using a computerized model for evaluating scheme designs is that the distribution of each parameter over the period under consideration is obtained. As an example the distribution of yields of sucrose over the 50-year period studied at Mount Edgecombe, for a soil with a TAM of 75 mm, and for a water duty of 4752 ha/cumec with 60 mm of water applied at an efficiency of 85%, is given in Figure 2. In terms of cash flow alone it is important to know how often different levels of production are likely to occur. The highest and lowest amounts of sucrose per annum obtained were 9,07 and 13,99 tons per hectare, whilst 84% of the values over a 50-year period lay between 11,0 and 13,5 tons per hectare per annum.

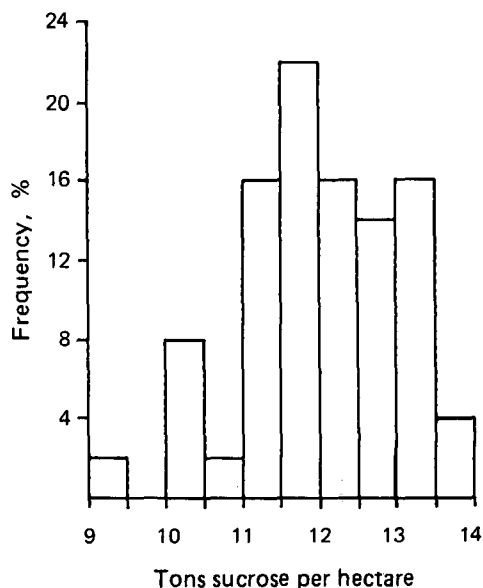


FIGURE 2 Frequency distribution of yields of sucrose per hectare

Conclusions

A computerized model to evaluate irrigation schemes for sugarcane should be a useful tool both for the practising agriculturist and the research agronomist. Its value is heavily dependent upon a reliable record of daily rainfall, preferably for a minimum of 20 years, and monthly mean evaporation data for a class A pan, based on at least 5 years of observations. Thereafter, the applicability of the model will depend on a knowledge of the available moisture content of the soil, the pattern of moisture removal from the soil by the crop, and the relationships between yield and evapotranspiration. These need to be confirmed in time by measurements, observations and experimentation under local conditions.

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