THE ESTIMATION OF THE WATER REQUIREMENTS OF SUGARCANE IN NATAL

By G. D. THOMPSON, C. H. O. PEARSON and T. G. CLEASBY

Summary

Replicated lysimeter trials on two sites have provided the means over the past three and a half years of measuring the potential evapotranspiration of sugarcane. The results indicate that the water requirements vary from a maximum of 0.24 inches per day in January to a minimum of 0.09 inches per day in June. It is shown that moisture deficits may occur at any time of the year and that the short periods of summer drought are most severe in suppressing crop yield.

Of the various methods by which evapotranspiration may be estimated from meterological measurements and calculations, it appears that the Class A Pan should be recommended when time and cost as well as reliability are taken into account. An average ratio slightly lower than unity is obtained between potential evapotranspiration and Class A Pan evaporation for periods of full canopy.

Introduction

Some knowledge of the water requirements of a crop is essential if an irrigation scheme is to be planned and operated intelligently. Whilst the amount of water applied per irrigation may be governed by the effective rooting depth of the plants and available moisture holding capacity of the soil, the frequency with which applications need to be made depends on the rate at which evapotranspiration takes place. And when irrigation is supplementary to poorly distributed but reasonably heavy summer rainfall it is also important to know the stage at which an irrigation cycle may commence without unnecessary wastage of water, and here again an appreciation of the rate of water use by the crop is invaluable.

With these aspects of irrigation in mind, experiments using non-weighing lysimeters have been conducted on the S.A.S.A. Experimental Farm at Chaka's Kraal and by the Tongaat Sugar Company to measure the water requirements of sugarcane over the past three and a half years. The amounts of rainfall and overhead irrigation have been measured in raingauges on the lysimeters, and the amounts of excess water percolating through the soil profile within the lysimeter tanks have been removed and measured at regular intervals. The differences between the amounts of precipitation and percolation over specific periods have given a measure of the amounts of water evaporated from the soil and transpired by the crop. The results for the plant crops of these experiments, and also those from a third layout on the Illovo Sugar Estates have been given in a previous paper presented to an earlier Congress by the authors (Pearson *et al*, 1961). The construction of the lysimeters, the location of the experimental sites and the techniques of operation were fully described and will not be presented here.

In order to account for variations in evapotranspiration from season to season and from area to area, it is valuable to establish even an approximate relationship between evapotranspiration and some easily measurable meterological factor or factors. Daily evaporation has been measured from both the Symons tank (a black tank 6' x 6' x 2' deep, sunk into the ground) and the Class A Pan in conjunction with the lysimetric work, and measurements of atmospheric temperature and humidity, run of wind and hours of sunshine have permitted estimates of evaporation to be calculated by the methods of Penman (1950) and Thornthwaite (1948).

Results and Discussion

The sugarcane crops in all instances but one were harvested at approximately one year old to avoid the errors introduced once the cane had lodged. Throughout the three crop cycles which have been completed the evapotranspiration was estimated over twenty-eight day periods, and the results are presented in Tables 1 and 2 for Chaka's Kraal and Tongaat separately.

The second ratoon crop at Tongaat was deliberately prolonged so that data could be obtained for a full canopy of cane over the September to December period. It is fortunate that the second ratoon data from this site proved to be quite as reliable as those from the plant crop, and the results can be accepted with confidence.

In retrospect it appears that calendar monthly periods would have been preferable to twenty-eight day periods, but the original intention to measure weekly evapotranspiration was modified progressively as it became apparent that short-period data for the lysimeters were extremely variable, and ultimately four-weekly periods were found to be the minimum for which reliable data could be presented. The variability of the short-period data is the result of differences in the moisture contents of the soil profiles at the beginning and at the end of such periods, the percentage error decreasing as the period is lengthened and the amount of total evapotranspiration is increased.

During the periods in the early stages of crop development when the sugarcane leaves form an incomplete canopy over the interrow, evaporation from the soil surface takes place to a significant extent. This is particularly true in the plant crop when bare soil is exposed to direct insolation, whilst transpiration in all crops is largely a function of the degree of ground cover. Total evapotranspiration under conditions of incomplete canopy may be governed to a large extent by the frequency with which the soil surface is wetted, and unless daily irrigation is applied the results will probably show poor repro-

Table 1

Measured Evapotranspiration at Chaka's Kraal

Plant		1st Ratoon		2nd Ratoon	
Period	Ins./day	Period	Ins./day	Period	Ins./day
				15. 8.61 — 11. 9.61	0.029
				12. 9.61 — 9.10.61	0.036
2.10.59 — 29.10.59	0.120	30. 9.60 — 27.10.60	0.044	10.10.61 — 6.11.61	0.070
30.10.59 — 26.11.59	0.089	28.10.60 — 24.11.60	0.089	7.11.61 — 4.12.61	0.058
27.11.59 — 24.12.59	0.194	25.11.60 — 22.12.60	0.154	5.12.61 — 1. 1.62	0.231
25.12.59 — 21. 1.60	0.204	23.12.60 — 19. 1.61	0.256	2. 1.62 — 29. 1.62	0.250
22. 1.60 — 18. 2.60	0.279	20. 1.61 — 16. 2.61	0.255	30. 1.62 — 26. 2.62	0.207
19. 2.60 — 17. 3.60	02.48	17. 2.61 — 16. 3.61	0.184	27. 2.62 — 26. 3.62	0.250
18. 3.60 — 14. 4.60	0.177	17. 3.61 — 13. 4.61	0.145	27. 3.62 — 23. 4.62	0.195
15. 4.60 — 12. 5.60	0.138	14. 4.61 — 11. 5.61	0.117	24. 4.62 — 21. 5.62	0.122
13. 5.60 — 9. 6.60	0.115	12. 5.61 — 8. 6.61	0.107	22. 5.62 — 18. 6.62	0.128
10. 6.60 — 7. 7.60	0.101	9. 6.61 — 6. 7.61	0.080	19. 6.62 — 16. 7.62	0.126
8. 7.60 — 4. 8.60	0.124	7. 7.61 — 3. 8.61	0.105		
5. 8.60 — 1. 9.60	0.122	4. 8.61 — 14. 8.61	0.065		
2. 9.60 — 29. 9.60	0.194				

Fiducial limits, 5% Level: Plant crop ± 0.012 ins./day
1st Ratoon ± 0.019 ins./day

Note: The second ratoon data are from one lysimeter only, the cane growth in the other two lysimeters having been affected by uncontrollable factors.

Table 2

Measured Evapotranspiration at Tongaat

Plant		1st Ratoon		2nd Ratoon	
Period	Ins./day	Period	Ins./day	Period	Ins./day
				22. 8.61 — 16. 9.61	0.012
				17. 9.61 — 14.10.61	0.078
5.10.59 — 4.11.59	0.027	29. 9.60 — 26.10.60	0.052	15.10.61 — 11.11.61	0.041
5.11.59 — 1.12.59	0.073	27.10.60 — 23.11.60	0.111	12.11.61 — 9.12.61	0.198
2.12.59 — 27.12.59	0.220	24.11.60 — 21.12.60	0.152	10.12.61 — 7. 1.62	0.163
28.12.59 — 23. 1.60	0.236	22.12.60 — 18. 1.61	0.227	8. 1.62 — 4. 2.62	0.185
24. 1.60 — 20. 2.60	0.245	19. 1.61 — 15. 2.61	0.234	5. 2.62 — 3. 3.62	0.160
21. 2.60 — 19. 3.60	0.186	16. 2.61 — 15. 3.61	0.275	4. 3.62 — 31. 3.62	0.191
20. 3.60 — 16. 4.60	0.158	16. 3.61 — 12. 4.61	0.152	1. 4.62 — 28. 4.62	0.164
17. 4.60 — 14. 5.60	0.158	13. 4.61 — 10. 5.61	0.103	29. 4.62 — 26. 5.62	0.142
15. 5.60 — 11. 6.60	0.110	11. 5.61 — 7. 6.61	0.074	27. 5.62 — 23. 6.62	0.085
12. 6.60 — 9. 7.60	0.081	8. 6.61 — 5. 7.61	0.059	24. 6.62 — 21. 7.62	0.072
10. 7.60 — 6. 8.60	0.096	6. 7.61 — 2. 8.61	0.060	22. 7.62 — 18. 8.62	0.089
7. 8.60 — 3. 9.60	0.096	3. 8.61 — 21. 8.61	0.073	19. 8.62 — 15. 9.62	0.132
4. 9.60 — 28. 9.60	0.129			16. 9.62 — 13.10.62	0.124
				14.10.62 — 10.11.62	0.149
				11.11.62 — 8.12.62	0.208

Fiducial Limits, 5% level: Plant crop ± 0.014 ins./day
1st Ratoon ± 0.018 ins./day
2nd Ratoon ± 0.014 ins./day

Pooled estimate, 5% level: ± 0.014 ins./day
1% level: ± 0.019 ins./day

ducibility. Where a trash layer is used to mulch the ratoon crops, as was done in these experiments, this factor would be of considerably smaller importance. Thus the data in Tables 1 and 2 for periods prior to approximately mid-January, when an essentially complete canopy had been formed, should be considered relative to the conditions of the experiments only. Thereafter, the results should constitute reliable estimates of potential evapotranspiration, since Cowan and Innes (1956) showed that evaporation under a canopy of sugarcane leaves was only one tenth of that from a fully exposed open water surface.

Irrigations throughout the experimental periods were applied twice weekly whenever rainfall failed to exceed the requirements of the crop.

For the sake of convenience the data for periods of full canopy in Tables 1 and 2 have been summarized by monthly periods in Table 3, and the general means calculated.

Table 3

Calculated Evapotranspiration for Calendar Months for Periods of Full Canopy only

Month	Chaka's Kraal — Ins./day				Tongaat — Ins./day				Overall Mean, Ins./day
	Plant	1st R	2nd R	Mean	Plant	1st R	2nd R	Mean	
January..	0.28	0.26	0.25	0.26	0.25	0.23	0.19	0.22	0.24
February	0.27	0.23	0.21	0.23	0.23	0.25	0.16	0.22	0.23
March ..	0.22	0.17	0.24	0.21	0.18	0.21	0.19	0.19	0.20
April ..	0.16	0.13	0.18	0.15	0.16	0.12	0.16	0.15	0.15
May ..	0.12	0.11	0.12	0.12	0.13	0.08	0.13	0.12	0.12
June ..	0.11	0.09	0.13	0.11	0.09	0.06	0.02	0.08	0.09
July ..	0.12	0.10	0.13	0.12	0.09	0.06	0.08	0.08	0.10
August	0.12	—	—	0.12	0.10	0.07	0.11	0.09	0.10
September	0.19	—	—	0.19	0.13	—	0.13	0.13	0.15
October	—	—	—	—	—	—	0.14	0.14	0.14
November	—	—	—	—	—	—	0.19	0.19	0.19
December	—	—	—	—	—	—	0.21	0.21	0.21

These data compare with mean summer and winter evapotranspiration of 0.24 inches per day and 0.16 inches per day respectively in Hawaii as reported for sugarcane by Campbell *et al* (1959), although peak values of 0.34 inches per day were measured there in the second summer of growth.

The full implications of the maximum daily evapotranspiration occurring in January may be realised by considering the following table, in which the available moisture per foot of soil in the major soil types of the cane belt (after Maud, 1962) is expressed as the number of days supply to a crop when evapotranspiration is 0.24 inches per day.

Table 4

Available Moisture for Various Soil Types Expressed as Number of Days Supply to Sugarcane in January

Soil Type	% Total area of Cane Belt	Avail. moist, Ins./foot	Approx. No. of days Supply in January per ft. of soil
Tugela Schist ..	3.2	0.92	4
Granite	13.0	1.22	5
T.M.S. (Ordinary)	19.3	0.71	3
T.M.S. (Mist Belt)	4.8	1.90	8
Dwyka Tillite ..	9.9	2.06	8½
Lower Ecca Shale	6.3	2.54	11
Middle Ecca Shale	8.3	2.19	9
Red Dolerite ..	8.0	1.95	8
Red Recent Sand..	7.1	0.44	2
Grey Recent Sand	6.9	0.28	1
Alluvium (Red) }	10.3	1.21	5
Alluvium }		3.07	13

The inadequacy of natural rainfall in supplying the full moisture requirements of the crop is illustrated in Figure 1 for the three crops harvested at Chaka's Kraal. It will be observed that the moisture deficits varied from 1.99 inches to 27.59 inches per crop, but these amounts must constitute improbable minima since runoff and deep percolation must inevitably have reduced the efficiency of the rainfall. These results also serve to emphasize the fact that moisture deficiencies invariably occur during the period of maximum growth from December to March, and that it is during this period that irrigation can be used to the greatest advantage.

All of the crops produced were more than adequately fertilized, the general applications being 200 lbs. N, 100 lbs. P_2O_5 and 200 lbs. K_2O per acre per crop. The yields and total amounts of evapotranspiration (E_t) for the crops are shown in Table 5.

These yields do exceed commercial yields of irrigated sugarcane in this area by a considerable amount, and the fact that the harvested areas were very small may account for this to a great extent. An interesting point arises, however, when it is considered that such high yields were fairly consistently obtained under conditions of potential evapotranspiration. It is possible that both the amount of water used by the crop and the yield may be less under the conditions which obtain commercially. Denmead and Shaw (1962) have shown for maize that the actual evapotranspiration falls below the potential level at remarkably low soil moisture tensions on days of high consumptive use. The point at which the phenomenon occurs is associ-

Table 5

Sugarcane Yield and Total Water Use

Station	Stage	Age of crop, months	Tons/acre 1/1000th ac. lysimeters	Tons/acre surrounding 1/80th ac.	Sucrose % Cane	Total water use, Inches
Chaka's Kraal	Plant	12	93.5	61.6	12.9	58.9
	1st Ratoon	10¼	79.5	67.3	—	43.7
	2nd Ratoon	11	68.0	52.3	10.8	42.1
Tongaat	Plant	12	76.0	55.8	11.9	49.6
	1st Ratoon	11	85.2	60.3	13.1	43.9
	2nd Ratoon	15½	68.0	69.5	14.5	61.3

ated with the visible symptoms of temporary wilt, and these are a common enough sight even in well irrigated sugarcane fields at midday in summer.

Growth measurements were taken concurrently on irrigated and unirrigated cane at the lysimeter site at Chaka's Kraal during the first and second ratoon stages of the experiment. The results are plotted in Figure 2 where the rainfall is also shown. The considerable effects on yield of short periods of drought during the height of the growing season are well illustrated. If N:Co.376 averages 9 tons of cane per acre per foot of stalk, then a difference between the mean growth rates of 0.70 inches per day during February, 1961, would have resulted in the loss of almost 4 tons of cane per acre over a period of a single week. The comparatively low value per day of winter irrigation may also be seen from these results. At this season the difference in growth rate between irrigated and unirrigated cane is seldom more than 0.1 inch per day, and it would only be in the event of the winter dry season persisting into August, September and October that its effects would compare with those of the short summer droughts.

The estimates of evapotranspiration for twenty-eight day periods of full canopy at Chaka's Kraal have been compared with the measured evaporation from a Symons Tank and a Class A Pan, and with the calculated values from the formulae of Penman and Thornthwaite. The original Penman formula was modified by using the observed regression constants given by Glover and McCulloch (1958) for the Durban radiation station. These allow for variations in latitude when treating the n/N term for estimating incoming radiation, and by using the more correct local values the correlation coefficient between measured evapotranspiration and calculated evaporation was improved from 0.83 to 0.89. The Penman estimates for the twenty-eight day periods were calculated from the mean meterological data for the same periods. This was considered to be justified after the mean values of evaporation calculated daily from the formula were not found to differ by more than 0.001 inches of evaporation per day from the single calculation of evaporation from the mean meterological data. The various results are presented in Table 6, where the relative F factors (E_t/E_o) are also given. The Class A Pan and Gunn Bellani radiation integrator were installed for the ratoon crops only.

Table 6

Summary of Evapotranspiration (Et) and Evaporation (Eo) Data and "F" Value for Periods of Full Canopy only.

	Plant	1 R	2 R	Mean	r	D.F.
Chaka's Kraal, Ins./day, Et	.139	.138	.183	.153	—	—
Eo, Symons Tank	.098	.108	.148	.118	0.87	21
Eo, Class A Pan	—	.158	.193	—	0.87	14
Eo, Penman	.120	.148	.165	.144	0.89	21
Et, Thornthwaite	0.72	.102	.115	.096	0.87	21
"F" factors (Et/Eo): Symons Tank	1.42	1.28	1.24	1.30		
Class A Pan	—	0.87	0.95	—		
Penman	1.16	0.93	1.11	1.06		
Thornthwaite	1.93	1.35	1.59	1.59		
Tongaat, Ins./day, Et	—	.129	.142	.135	—	—
Ml./day, Gunn Bellani	—	7.15	8.47	7.81	0.90	19

The various Eo values and the Gunn Bellani measurements have been plotted against Et for each twenty-eight day period in Figure 3. The correlation coefficients (r) are reasonably encouraging, although the extent to which inaccuracies in the estimates of Et have affected the results cannot be determined. The relative values are very much in line with results obtained by Stanhill (1961) who worked with lucerne. His correlation coefficients for monthly periods, compared with the twenty-eight day values from Table 6 above are as follows:

	Stanhill	*Chaka's Kraal*
Penman	0.96	0.89
Class A Pan.. ..	0.95	0.87
Symons Tank ..	0.94	0.87
Thornthwaite ..	0.94	0.87

It can be confirmed on the basis of these results that, taking into account costs of equipment and the time required to record the various meterological readings and to carry out the calculations where necessary, the Class A Pan is to be preferred as a means of estimating potential evapotranspiration. The fact that the ratio of Et to Eo (Class A Pan) is close to unity may be regarded as a further advantage from a practical point of view. However, the initial results with the Gunn Bellani radiation integrator are also encouraging, and this aspect of the research is to be pursued. The fact that the Gunn Bellani averages for twenty-eight day periods gave a better correlation with evapotranspiration (0.90) than with measured total solar radiation from the Durban Station (0.80) is difficult to explain at this stage, and it would also appear that over shorter periods the latter correlation deteriorated rapidly.

Acknowledgments

Acknowledgments are due to Mr. H. Dicks for his help with the statistical treatment of the experimental results and to Mr. C. Booth for the growth measurement data.

References

Campbell, R. B., Jen-Hu Chang and D. C. Cox, (1959), Evapotranspiration of Sugar Cane in Hawaii as Measured by In-Field Lysimeters in Relation to Climate, Proc. Int. Soc. Sugar Cane Techn. 10th Congress.

Cowan, I.R. and R. F. Innes, (1956), Meteorology, Evaporation and the Water Requirements of Sugarcane, Proc. Int. Soc. Sugar Cane Techn. 9th Congress.

Denmead, O.T. and R. H. Shaw, (1962), Availability of Soil Water to Plants as Affected by Soil Moisture Content and Meteorological Conditions, Agron. Jour., 54, 385-390.

Glover, J. and J. S. G. McCulloch, (1958), The Empirical Relation between Solar Radiation and Hours of Sunshine, Jour. Roy. Met. Soc., 84, 172-175.

Maud, R. R., (1962), Soil Moisture Relationships of Some Natal Sugar Belt Soils, Proc. of S.A. Sugar Tech. 36th Congress.

Pearson, C. H. O., T. G. Cleasby and G. D. Thompson, (1961), Attempts to Confirm Irrigation Control Factors Based on Meteorological Data in the Cane Belt of South Africa, Proc. of S.A. Sugar Techn. 35th Congress.

Penman, H. L., (1950), Evaporation Over the British Isles, Quart. Jour. Roy. Met. Sox., 76, 372-82.

Stanhill, G., (1961), Comparison of Methods of Calculating Potential Evapotranspiration from Climatic Data, Israel J. Agric. Res., 1, 159-171.

Thornthwaite, C. W., (1948), An Approach towards a Rational Classification of Climate, Geographical Review, 38, 55-94

FIGURE I

WATER BALANCE FOR THREE SUGARCANE CROPS

CHAKA'S KRAAL EXPERIMENTAL FARM

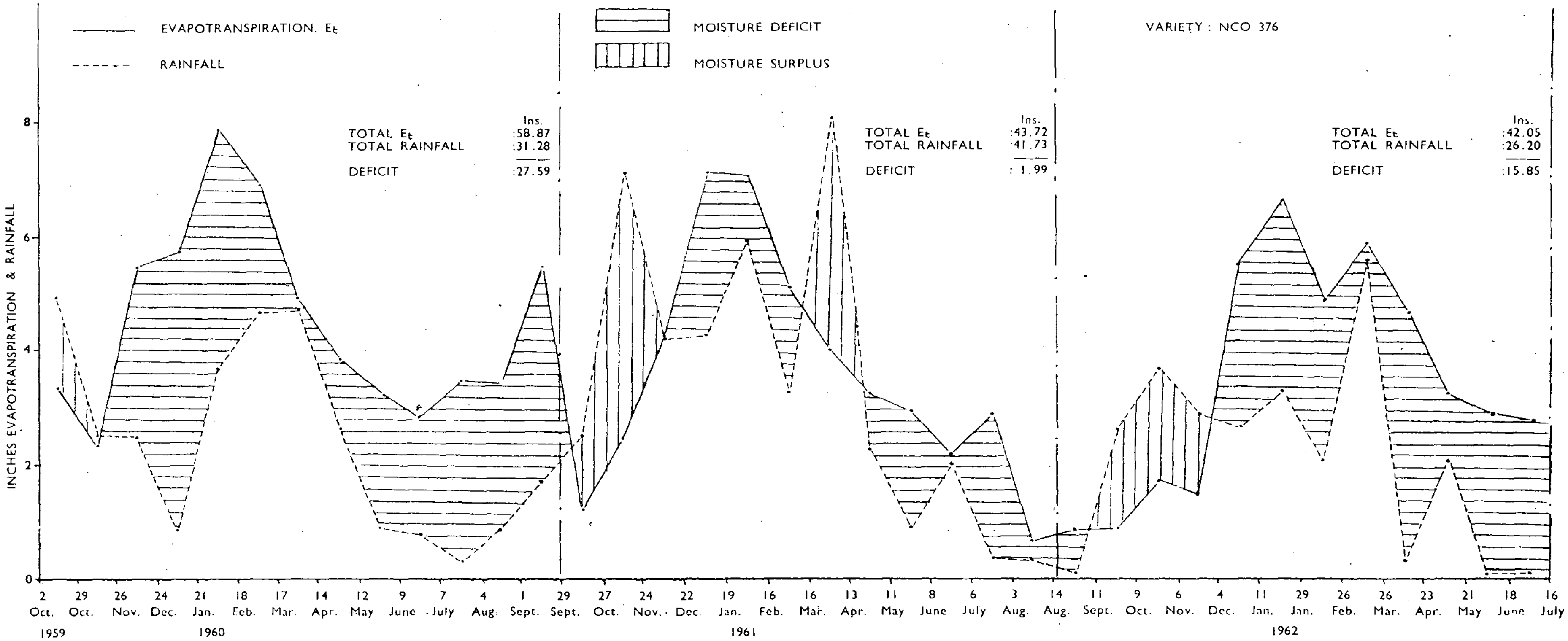
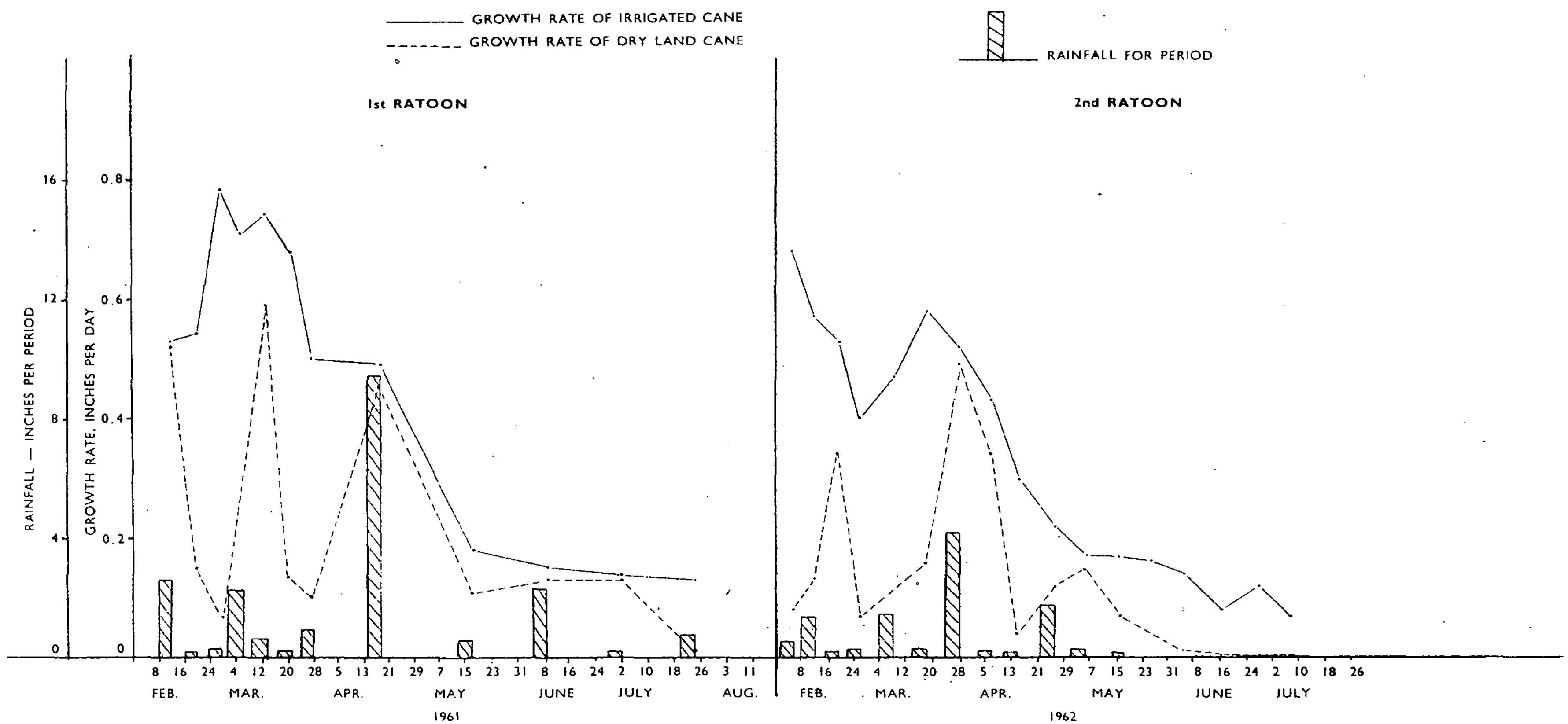


FIGURE 2

COMPARATIVE GROWTH RATES

IRRIGATED AND DRY LAND SUGARCANE

CHAKA'S KRAAL EXPERIMENTAL FARM, 1961/62.



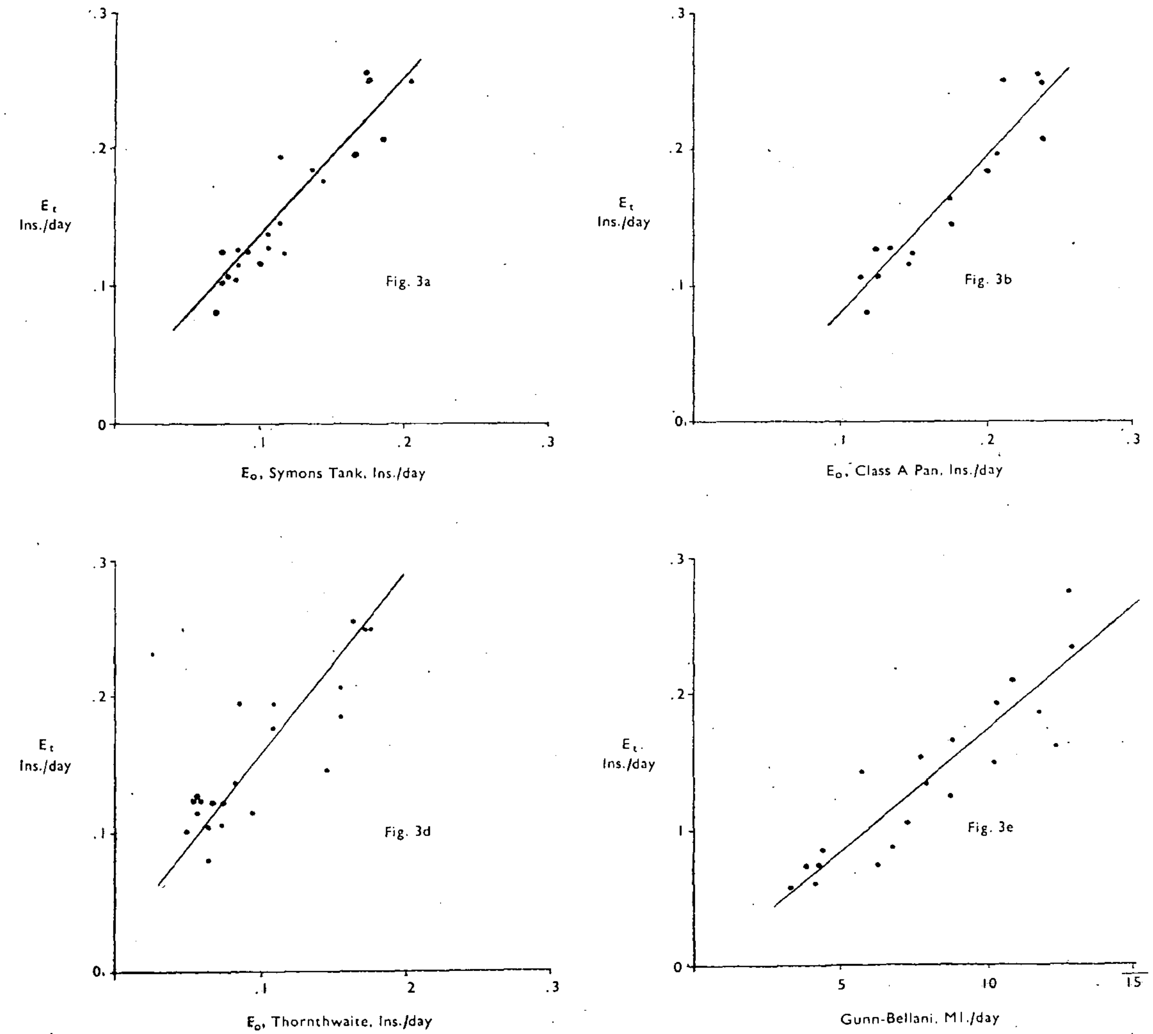


FIGURE 3 — CORRELATIONS BETWEEN E_t AND MEASURED OR CALCULATED VALUES OF E_o AND GUNN-BELLANI VALUES.

Mr. du Toit said that he considered that, due to the efforts of a small group of people, South Africa was ahead of other countries in the collection of data concerning irrigation.

In some countries irrigation was not necessary to obtain large yields, while again in some countries irrigation was essential to produce a crop at all. In South Africa cane could be grown under dry-land conditions but irrigation under certain conditions could increase the crop enormously. It was therefore of great importance to have all the data procurable and the information given in the paper gave an excellent lead and he hoped that further information of this kind would be accumulated in the near future.

Mr. R. A. Wood asked if there was any evidence that advective energy might seriously affect the estimation of water requirement.

Mr. Thompson replied that this was so. Since the present equipment was installed studies had been made on net radiation and where previously there had been a tendency to criticise the Penman equation, now that net radiation was being measured it was found that the results given by this equation for net radiation were just about right for our conditions. Comparing the estimated figures for evapotranspiration with those given by the lysimeter tanks it was found at times that the former were only half that of the latter. This could only be due to advective energy—heat energy coming in or going out due to wind—and the whole cane belt could be subject to advective energy from the adjacent areas. From the data obtained so far, Mr. Thompson said he was sure that advective energy could be a primary factor in evapotranspiration. Advective energy was very difficult to measure but it was hoped to study how much advective energy affected the consumptive use of water by a sugarcane crop.

Dr. Cleasby said that a very important point was the economics of irrigation. From the experimental work done up to now there was no doubt that the response to a certain amount of water applied was economical, but when this was tried out on a field scale, was it economical or not? The difference between an experiment and field practice was that in an experiment one was sure that one got the water into the soil where, and when, it was wanted, but in a field this was not so simple, for to get the water into the soil was a major problem, because of factors such as run-off.

Table 4, which was the practical interpretation of the data, showed that ordinary T.M.S. soil need be given only three days supply in January. This was due to the available water per foot in such soils being compensated for by the depth, sometimes as much as three feet, from which the available water could be drawn.

Mr. Hill asked if the difference in evaportranspiration in the summer months between Chaka's Kraal and Tongaat might be due to some soil difference.

Mr. Thompson said this was most probable and the only other factor might be due to difference in the micro-climate in the two areas. Until the rooting depth, as pointed out by Dr. Cleasby, was known for each soil type the data could not be interpreted fully. Work on this aspect would be started soon at the Experiment Station.

Mr. Wilson (in the Chair) stated that the work reviewed by Mr. Thompson was that done so far, but plans for expanding this work as mentioned by him were now being made. It was planned that a physiologist should be appointed to the staff to collaborate in such studies and this whole fundamental and vital work would be tackled on a broad front.