Project S24.

PROJECT S24 - LYSIMETER

FINAL REPORT ON

"Water Consumption - Growth Relationships of the Variety Q80"

SUMMARY

Total crop water usage ranged from 1.46 m to 2.06 m for 12 month crops and from 1.72 m to 2.04 m for 13 month crops.

Minimum and maximum daily growth rates ranged from 0.3 to 5.1 and 25.1 to 34.4 mm per day respectively. After initial establishment, growth rates of first emergent and later emergent shoots were comparable. Minimum and maximum daily E_T rates ranged from 1.3 to 2.8 and 9.2 to 12.4 mm per day respectively. A maximum of 8.8 mm per day was found as the mean for the peak growth period.

Significant, positive correlations were generally found between E_T and E_o and these correlations improved after about 75 per cent of canopy development had been reached. Indications that either standard or elevated pan data could be used to estimate E_T were obtained provided appropraite pan factors were applied. Pan factors, slightly above generally quoted values, were determined for an elevated "Class A" pan.

Although significant relationships between mean daily growth rate and E_T (and to a lesser degree E_o) were established in some instances, and between mean daily growth rate and mean daily temperature; in all crops, a positive highly significant relationship was found between mean daily growth rate (M.G.R.) and either mean daily temperature ($\overline{T}$) and E_T or temperature ($\overline{T}$) and E_o of the form

$$\text{M.G.R.} = a + b_1 \overline{T} + b_2 E_T \text{ (or } E_o\text{)}.$$

Introduction

Rain in the Lower Burdekin District falls during a very short period, much of it being of high intensity and consequently low "effectiveness". Greater than 99% of the area is heavily dependent on irrigation for much of the growing period. However little was known of the consumptive use of water by cane in the area.

A drainage lysimeter was constructed and installed at the Ayr Sugar Experiment Station in late October 1964, and after a settling-in period was planted to sugar cane in June, 1965 with the express purpose "of determining the amount of water used by cane and lost by evaporation from the soil, when the crop is growing unretarded during the period planting to harvest" i.e. to measure evapotranspiration (E_T) while maximising yield. Additionally, an attempt to relate E_T to water evaporation (E_O) from a U.S. Weather Bureau "Class A" pan in close proximity to the crop was to be carried out. Campbell et al (1959), Thompson et al (1963), and Metelerkamp (1968) have related E_T to E_O, after crop water use was determined, to provide an emperical estimate of E_T.

Thornwaite (1948) coined the term potential evapotranspiration (E_{TP}) to describe the E_T for a fully developed plant canopy, such E_{TP} being subject only to the limitations imposed by prevailing meteorological conditions, Cowan & Innes (1956). Since maximum cane sugar yields depends not only on cane yields but also sucrose content of the crop, maximising yield does not necessarily imply that maximum sugar yields or, more particularly, maximum economic return per hectare will result.

By maintaining "unretarded" growth in this study, it was intended to avoid the rapid drop in E_T below E_{TP} when soil moisture tension exceeded one bar as reported by Moberly (1974). Previously Demeade and Shaw (1962) and Milthorpe (1960) had shown that once non-meteorlogical factors limited transpiration, actual use rates were influenced little by increases in atmospheric demand for water.

A "fully developed" plant canopy giving complete ground cover has been a theoretical pre-requisite to E_{TP}, and the influence of plant ground cover on E_T is well recognised. However, in sugar cane, and several other crops, maximum E_T rates have been attained before "complete ground cover" was achieved; Anon (1966) reported, for ratoon cane in South Africa, that maximum E_T values had been reached at as low as 40% vertical cover stage of canopy development.

Soil moisture balance studies, as applied in this investigation, are generally only suited to the determination of E_{TP}.

Campbell et al report that the pan factor (or ratio E_T/E_O) increases from about 0.4 for cane with up to 25% canopy development, to 1.0 for fully canopied cane. Application of the pan factor appropriate to the stage of canopy development enables

The Soil

The profile consists of 32 cm of very dark brown** sandy clay loam overlying 60 cm of dark yellow brown** sandy clay loam with a further 43 cm of dark yellow brown** light sandy clay; a Gn 2.42 according to Northcote (1971). After an initial period of consolidation, it was found to have a very low infiltration rate. Gypsum at 20 tonnes per hectare was applied soon after installation to improve the infiltration rate; a further application of five tonnes per hectare was made after harvest of the second plant crop.

The moisture release characteristics for the soil in the suction range 0.1-15 bar have been determined and are shown in Fig. 2.

Irrigation water used for the study was of good quality:-
Conductivity 0.33 mmho/cm; total dissolved solids 194 mg/l; 0.36 me/l residual HCO_3^-; and a low solium hazard.

Growth Measurements

The variety chosen for study was Q 80. Cane growth was measured as stalk elongation from a reference point (the lip of the lysimeter) to the last exposed dewlap. In the first crop cycle, ten shoots were chosen at random from the lysimeter and the equivalent sections of each immediately adjacent row for these weekly measurements.

For these measurements in the second crop cycle, a similar number were chosen from the first emergent shoots ("primary shoots") and also from the tillers that emerged two to three weeks later ("secondary shoots"). Growth measurements were made weekly in the plant crop and fortnightly in each of the ratoon crops. Guy wires were strung to minimise lodging and canopy disturbance.

Rainfall, Evaporation of Temperature Measurements

Rainfall & daily maximum and minimum temperature were recorded at a nearby meteorological site. A thermohygrograph was used to continuously record temperature and relative humidity throughout the second crop cycle.

Evaporation (E_0) from a U.S. Weather Bureau "Class A" pan was recorded throughout all crops. For the initial plant crop and half of the subsequent ratoon crop, the pan was situated with the water surface at 0.3 m above ground level. Thereafter, the pan was placed on a stand adjacent the lysimeter area with the water surface at 3 m.

The relationship between E_T and evaporation from the "Class A" pan was examined for each irrigation cycle in each crop.

** wet colours after Munsell

Relationship between Growth Rate and Temperature

Analysis of stalk elongation rates and temperature data revealed that highly ($P \geqslant 0.01$) significant correlations ($r \geqslant 0.81$) existed between these parameters in all crops in this study. These correlations were slightly higher in the crops of the second cycle. This can probably be attributed to a better estimate of mean daily temperature being available from the continuous recording of temperature on a thermo-hygrograph during those periods.

From this analysis, the temperature - dependence of growth was such that stalk elongation rates increased rapidly once mean daily temperature exceeded 24°C (Fig. 4). This temperature can therefore be considered as the index of the peak growth period which extends from late September - early October through to April, as shown by the data of table 2. Yates (1967) and Kingston (1972) have reported similar growth rate decline for mean daily temperatures below 22°C.

Growth Rates - "Primary" VS "Secondary" Shoots

In all correlation analysis, only the growth rates of the "primary" shoots are considered. This has been done since, in the second crop cycle, growth measurements on the both groups of shoots revealed that once the initial establishment phase was passed (i.e. four to five leaf stage), then growth rates for the remainder of the period were very similar, especially if the percentage survival to harvest of the initially selected shoots is considered. Comparable growth rates of the lysimeter "primary" and "secondary" shoots are shown in table 3, together with similar growth rates for immediately adjacent sections of row.

TABLE 3 - Averages of mean daily growth rates (mm/day) for "primary" and "secondary" shoots in the lysimeter and adjacent row sections.

	"Primary"			"Secondary"		
Crop	Left	Lysimeter	Right	Left	Lysimeter	Right
P	11.6	12.1	12.2	10.9	11.0	11.6
1R	12.0	12.8	11.0	11.8	10.4	10.3
2R	10.9	12.2	11.9	10.4	10.2	10.4

With each group of shoots, there is good agreement amongst growth rates for the lysimeter and adjacent row sections.

Relation of E_T to E_O

Examination of the data for the period planting (or ratooning) to harvest showed that in only, three of the five crops was there a highly significant ($P \geqslant 0.01$) correlation ($r \geqslant 0.73$) between these two parameters with a significant relationship ($P \geqslant 0.05$) in one other crop.

However, if the data examined is restricted to the period

Q 80 1R	E_T mm/day	6.4	2.8	10.7	7.7
	E_T/E_{OE}	0.88	0.50	1.49	0.96
Q 80 2R	E_T mm/day	5.0	1.3	10.4	6.1
	E_T/E_{OE}	0.74	0.25	1.70	0.83

+ Calculated for data from 11 weeks to harvest.

* Mean day temp. $> 24^{\circ}$C.

Plant crops have a higher mean daily E_T, higher minimum, maximum, and peak growth E_T values than their subsequent ratoon crops. Similarly, they have higher E_T to pan evaporation ratios throughout. The minimum E_T values of table 4 indicate that, although stalk elongation has slowed to low rates, significant consumptive use continues during sucrose accumulation (Rostron, 1971).

Relationship between Growth Rate, E_T, and E_0.

Generally significant positive relationships existed between mean daily stalk elongation rate and E_T for the corresponding period. Table 6 summarises these relationships and that of mean daily stalk elongation rate and pan evaporation. Despite the relationship outlined earlier between E_T & E_0 the relationship of mean daily stalk elongation rate to mean daily E_0 is not as strong.

TABLE 6 - Summary of correlation analyses between mean daily stalk elongation rate (M.G.R.) and mean daily E_T and mean daily E_0.

Crop		M.G.R. vs. E_T			M.G.R. vs. E_0	
	r	S.E. of residuals mm/day (growth)	P≥	r	S.E. of residuals mm/day (growth)	P≥
Q 80 P	0.45	7.46	0.05	0.31	7.93	N.S.
Q 80 1R	0.42	8.99	N.S.	0.49	8.64	0.05
Q 80 P	0.57	5.75	0.01	0.76	4.56	0.01
Q 80 1R	0.87	4.09	0.01	0.72	5.82	0.01
Q 80 2R	0.71	5.69	0.05	0.55	6.13	N.S.

As previously indicated, the very strong relationship between temperature and growth rate was of the form

$$\log (M.G.R.) = m\bar{T} + b.$$

where M.G.R. = mean daily stalk elongation rate
$\bar{T}$ = mean daily temperature (°C).

Although positive relationships have been demonstrated between M.G.R. and $\bar{T}$ mean daily E_T, or mean daily E_0 individually, when the relationship between M.G.R. and either $\bar{E}_T$ and $\bar{T}$ or $\bar{E}_0$ and T together, was examined very strong, positive, linear relationships of the form.

$$M.G.R. = a + b_1 \bar{T} + b_2 E_T \text{ (or } E_0)$$

were found. Table 7 summarises these correlation analyses between

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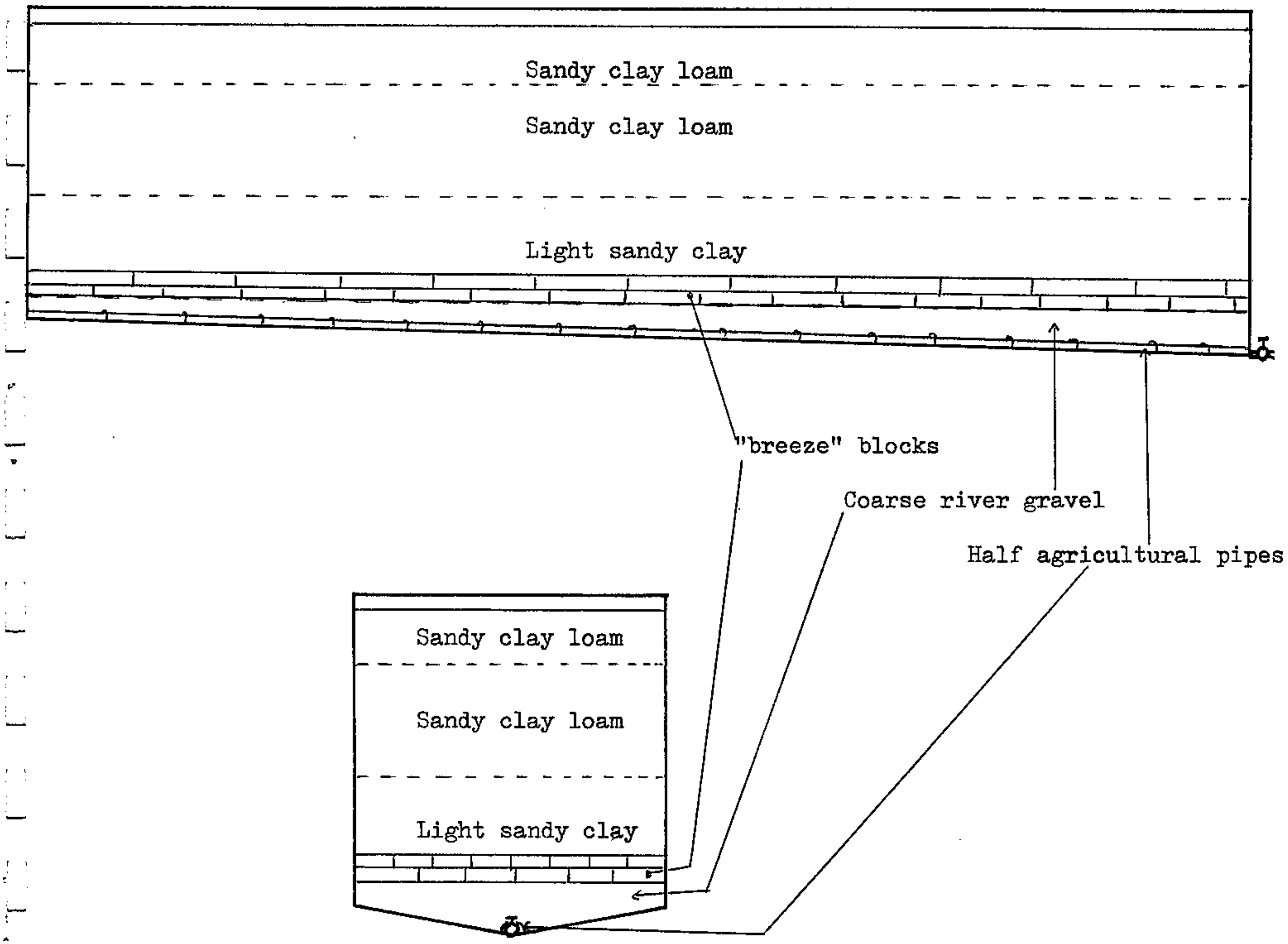
Figure 1

Lysimeter - Schematic Diagram



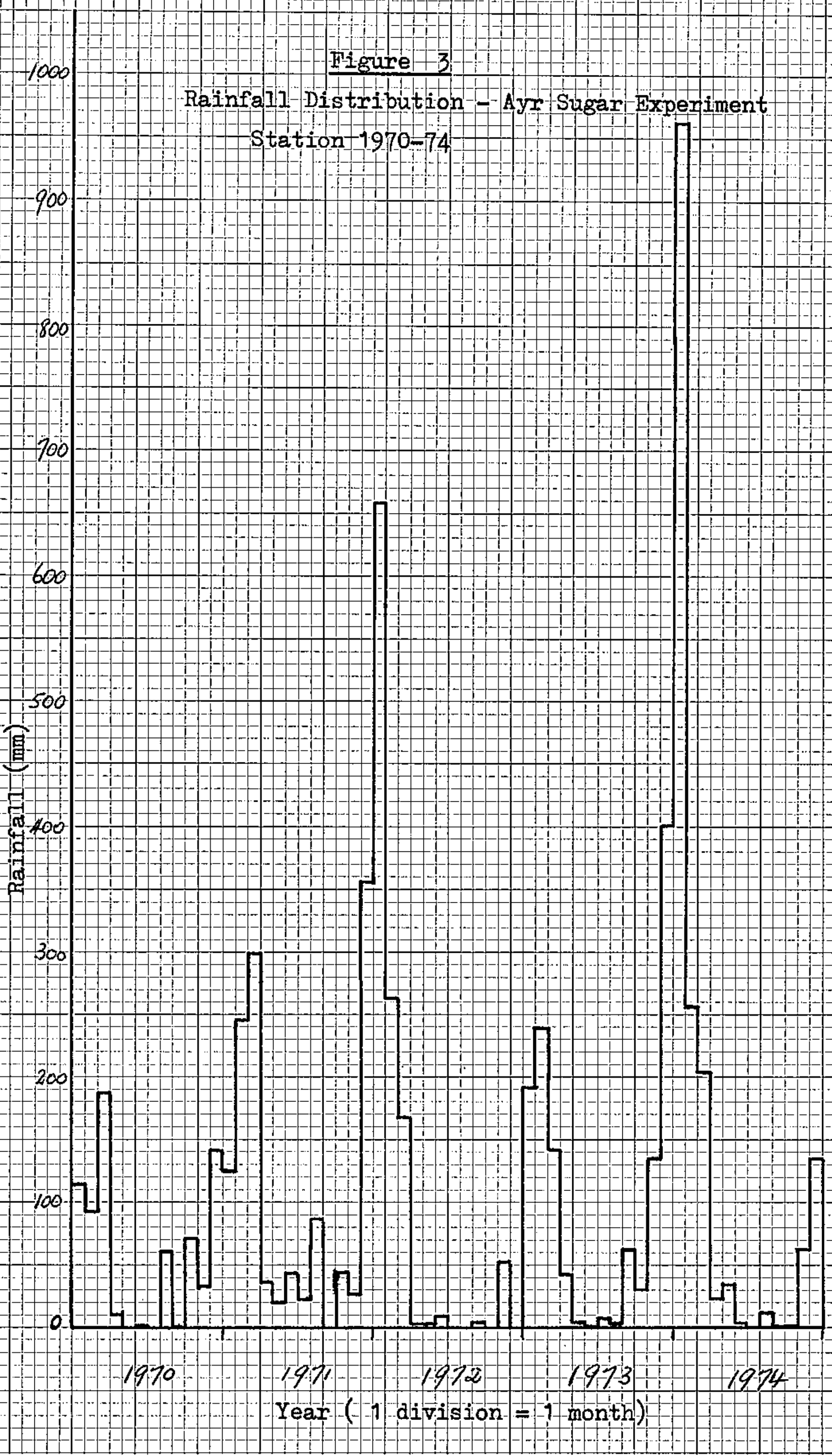


Figure 3

Rainfall Distribution - Ayr Sugar Experiment Station 1970-74

APPENDIX 1

Summary of Correlation Analyses for E_T vs E_o ($E_T = mE_o + b$)

(a) Full Crop Data

Crop	r	S.E. of residuals (mm/day)	P
P*	0.730	1.31	$\geqslant 0.01$
1R*	0.780	1.21	$\geqslant 0.01$
+P	0.713	1.91	$\geqslant 0.01$
1R	0.548	2.22	$\geqslant 0.05$
2R	0.409	2.24	n.s.

+ E_t estimate available only after growth measurements commenced

(b) Period from Start of Growth Measurements

P*	0.739	1.64	$\geqslant 0.01$
1R*	0.801	1.15	$\geqslant 0.01$
P	0.713	1.91	$\geqslant 0.01$
1R	0.681	1.32	$\geqslant 0.01$
2R	0.423	2.22	n.s.

(c) From 75 % Canopy to Harvest

P*	0.660	1.30	$\geqslant 0.01$
1R*	0.781	1.21	$\geqslant 0.01$
P	0.728	1.94	$\geqslant 0.01$
1R	0.824	0.93	$\geqslant 0.01$
2R	0.469	2.38	n.s.

* P data correlations with E_o from standard "Class A" pan, 1R correlations with E_o from standard pan to full canopy and thereafter with water level in pan at 3 m.

estimation of E_T from E_O.

Considerable variations in daily water use rates are reported in the literature, crop means ranging from 3.9 to 8.6 mm/day with minima and maxima between 2.3 to 6.4 and 4.8 to 15.8 mm/day respectively. E_{TP}/E_O ratios, crop averages ranging from 0.94 to 1.00, were similar for different countries, with considerable support for a pan factor of approximately 0.40 for young cane and 1.0 for fully canopied cane, although this latter figure ranged from 0.95 to 1.7. For a 12 to 13 month crop, total water requirement ranged from 1.28 to 2.29 m.

Methods & Materials

Lysimeter The installation comprises a 6.4 m long x 1.5 m wide steel tank (of 6.4 mm M/S plate) with a shallow V- base sloping along the long axis at 1.8 - 2.0 m deep. To the deepest end, a gate valve was fitted to enable complete drainage of the tank. Soil in the tank is 1.4 m deep; this was taken from the pit during tank installation and returned to the tank in correct sequence overlying drainage meterial of washed river gravel, "breeze" blocks*, and a thin layer of sand. (Fig. 1). To collect rainfall and contain irrigation water, 15 cm of the sides of the tank protrude above the soil. A single row of cane was planted through the long axis, and a 10 x 40 m buffer area was planted to cane around the tank.

Irrigation and Cultivation

The lysimeter and buffer area were furrow irrigated when soil moisture tension at 0.23 m reached 0.25 bars, in order to achieve E_{TP} and "unretarded" cane growth. Each irrigation was sufficient to cause 25-30% of the applied water to be collected as percolate from the lysimeter.

Additional tensiometers at 0.56 m and 0.91 m were used to monitor changes in soil moisture tension in the remainder of the profile between irrigations. Evapotranspiration (E_T) was calculated for each irrigation cycle as:-

$$E_T = \text{Irrigation} + \text{Rainfall} - \text{Drainage} + \text{Soil Moisture Depletion.}$$

The lysimeter and immediately adjacent area were cultivated (using garden fork and spade) in a similar sequence to commercially grown fields. The bulk of the buffer area was cultivated in the normal manner using tractor-mounted implements; the district practice of hilling up was followed in all crops. Also planting and ratooning operations were carried out as closely as possible to general district practice, with the exception that planting time was delayed to approximately two months after general planting. Nitrogenous fertilizer (Urea or Nitram) was applied at 101 and 135 kg N per hectare to plant and ratoon crops respectively as a single application when the crops were 3 to 4 months old.

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* very porous coke-cement bricks

Results & Discussion

Total crop water use

Total E_T for each of the crops, together with yield and water use efficiency date are shown in table 1.

TABLE 1 - Summary of Crop Yields, Age, E_T, and C.C.S. for crops grown in the lysimeter at the Ayr Sugar Experiment Station (Variety Q 80).

Crop	Time of Harvest	Age (Months)	Rainfall (mm)	E_T (mm)	Yield tonnes /ha.	Yield tonnes /10mmE_T	C.C.S.
P	July, 1966	13	675.6	2037.1	247.66	1.22	9.6
1R	Aug., 1967	13	856.0	1722.1	185.68	1.08	15.1
P	July, 1969	12	269.2	2042.2	238.08	1.17	14.0
1R	July, 1970	12	553.7	2067.6	228.26	1.10	14.3
2R	June, 1971	11	1082.0	1585.0	176.86	1.12	14.2

The data shown in table 1 are reasonably well supported by Thompson & Boyce (1968) and Boyce (1969) who, in field experiments have reported yields of 0.93-1.23 tonnes cane/10 mm from lysimeter studies, (Thompson & Boyce (1971)), with an irrigation schedule similar to that applied above.

A large deficiency between rainfall and total E_T exists, and this is shown table 2, rainfall distribution being shown in Fig. 3. With rare exceptions, rainfall effectiveness in the lysimeter would be 100%, although in the buffer it would be somewhat lower since this was subject to normal run-off conditions.

TABLE 2 - Mean day temperature, Mean Rainfall, and Mean Evaporation at Ayr.

Month	Mean Day Temp. (°C) 20 yrs.	Mean Rainfall (mm) 20 yrs.	Evaporation mm/day 9 yrs.
July	18.5	10.1	3.7
August	20.7	14.6	4.8
September	23.7	6.9	6.1
October	26.4	18.3	7.2
November	27.9	41.0	8.1
December	28.4	118.3	7.8
January	28.0	256.7	6.6
February	27.5	259.4	6.0
March	26.7	186.1	5.7
April	25.0	39.4	5.5
May	22.2	52.2	4.3
June	19.3	31.7	3.6
Annual total		1034.7	2110.1

during which growth measurements were possible (i.e. after the four to five leaf stage), highly significant, positive correlations ($P > 0.01$) were obtained in all but one crop. (Appendix 1). Higher correlation co-efficients and lower standard errors of residuals were demonstrated for periods extending from the near "full canopy" stage onwards.

Although direct comparisons are not possible, that generally highly significant correlations were obtained between E_T and E_O irrespective of whether E_O was measured from a standard E_{OS} or elevated (E_{OE}) pan, or from a pan raised after the "full canopy" stage had been reached suggests that E_O could adequately reflect the changes in E_T throughout a crop. It appears that better relations between E_T and E_{OS} for young cane, and E_T and E_{OE} for full canopied cane might not apply. E_T could then be estimated using either pan provided a relevant pan factor were applied. For an elevated pan, appropriate factors are shown in table 4. Factors for a standard pan (E_T/E_{OS}) for the initial plant crop are also shown. It is apparent from Table 4 that a higher pan factor is necessary to estimate E_T from E_{OS}, although the E_T/E_{OS} data is from a single crop only.

TABLE 4 - Pan factors (E_T/E_{OE}) for sugar cane at Ayr as affected by crop age.

Crop age (weeks)	0.12	12.16	16.20	20.24	24.28	28
Groundcover %	0.50	50.75	75			
Pan factor (E_T/E_{OE})	0.52	0.67	0.93	1.05	1.19	1.01
Pan factor (E_T/E_{OS})	n.d.	0.81	1.03	1.48	1.84	1.17

n.d. = not determined

Daily Evapotranspiration Rates

Table 5 contains a summary of E_T data for this investigation. Daily E_T values are those calculated for each irrigation cycle.

TABLE 5 - Mean daily evapotranspiration rates (E_T) and the ratio of E_T to standard or elevated "Class A" pan evaporation for sugar cane at Ayr.

Crop		Crop Mean	Min.	Max.	Mean for peak growth *
Q 80 P	E_T mm/day	6.0	1.6	9.5	7.3
	E_T/E_{OS}	1.13	0.48	2.60	1.20
Q 80 1R	E_T mm/day	4.6	1.5	9.2	6.0
	$E_T/E_{OS}:E_{OE}$	0.77	0.36	1.45	0.85
Q 80 P	E_T mm/day	7.9	2.5	12.4	8.8
	E_T/E_{OE}	0.91^+	0.58	1.61	1.17

M.G.R., $\bar{E}_T$, and $\bar{T}$, and M.G.R., $\bar{E}_0$ and $\bar{T}$ for each of the crops.

TABLE 7 - Summary of correlation analyses
(a) M.G.R. $= f(\bar{E}_T, \bar{T})$

Crop	a	b_1	b_2	Sr	Se	R^2	r
Q 80 P	-57.244	3.339	-1.471	1100.59	357.33	0.755	0.869**
Q 80 1R	-45.178	2.737	-1.443	1057.76	610.10	0.634	0.796**
Q 80 P	-38.803	1.939	-0.501	882.56	393.78	0.691	0.831**
Q 80 1R	-34.422	1.423	2.066			0.903	0.950**
Q 80 2R	-32.499	1.579	1.197	477.58	116.88	0.803	0.896**

**: P≥0.01

(b) M.G.R. $= f(\bar{E}_0, \bar{T})$

Q 80 P	-55.897	3.220	-1.505	1114.94	342.97	0.765	0.875**
Q 80 1R	-40.604	2.477	-0.943	1012.21	655.65	0.607	0.779**
Q 80 P	-34.837	1.575	1.473	960.17	316.17	0.752	0.867**
Q 80 1R	-41.266	2.341	-0.155	799.64	179.30	0.817	0.904**
Q 80 2R	-43.720	2.601	-1.100	423.69	170.77	0.713	0.844**

**: P≥0.01

Sr = deviation due to regression.
Se = unexplained error.
R^2 = unadjusted co-efficient of multiple determination.
r = correlation co-efficient.

Conclusions

The total water requirements of sugar cane at Ayr appeared to be in reasonably good agreement with those reported for other countries.

Significant, positive correlations established between E_T and pan evaporation for cane with a well developed canopy suggest that pan evaporation data could be used to provide a satisfactory estimate of E_T for such cane. A less reliable estimate of E_T is possible for cane from the four-five leaf stage to harvest. The limited comparison available also suggests that no advantage accrues from using standard, elevated, or a combination of both pan data to estimate E_T. Pan factors determined are generally higher than those reported elsewhere, although this may be a varietal influence.

Once established, all shoots have a fairly comparable growth rate. Daily growth rates are closely related to daily E_T rates and temperature. The practical implication is to avoid any soil moisture stress level which reduces E_T during the peak growth period. Daily E_T values are also related to the degree of canopy development.

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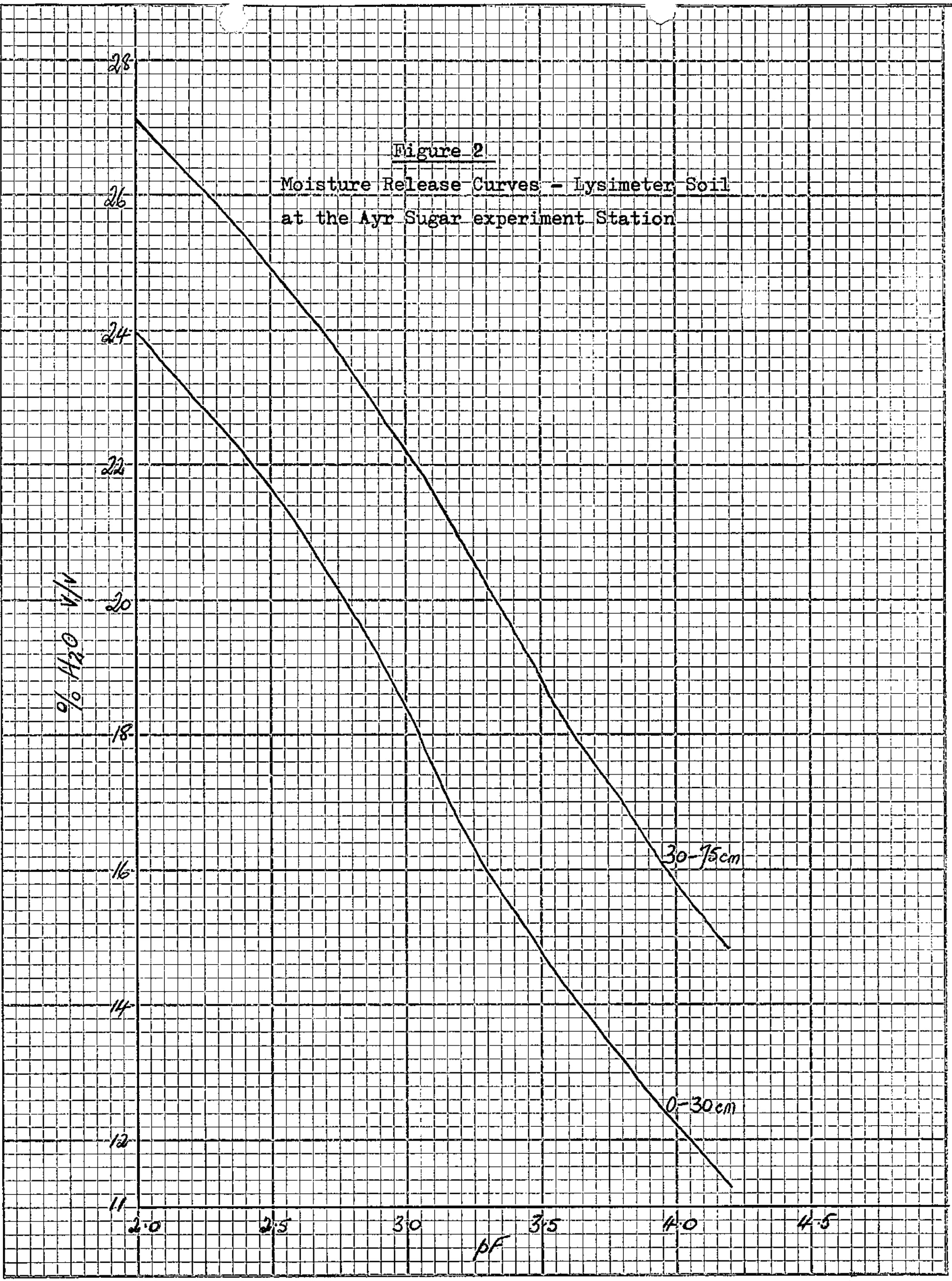

Figure 2

Moisture Release Curves - Lysimeter Soil
at the Ayr Sugar experiment Station

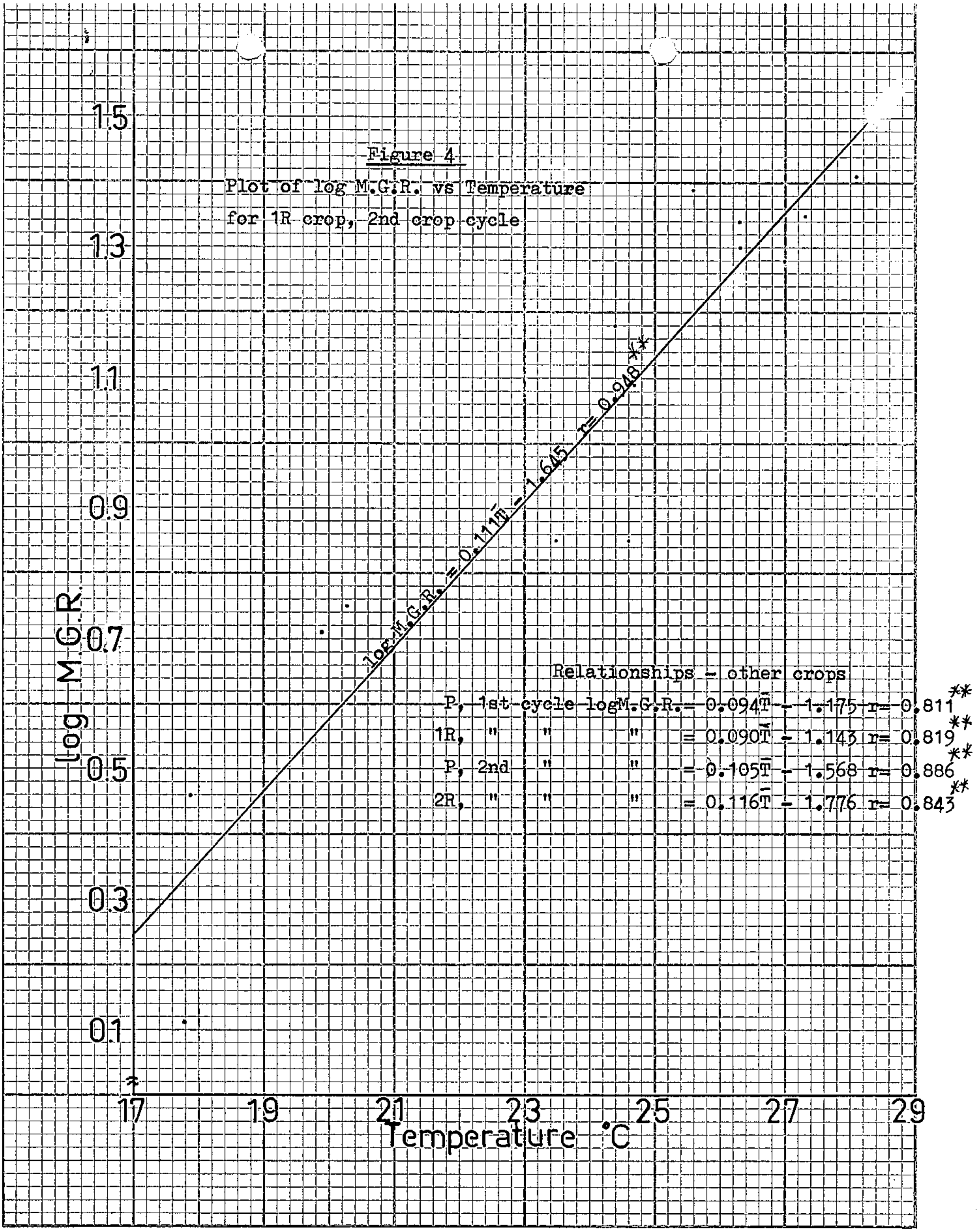

Figure 4

Plot of log M.G.R. vs Temperature
for 1R crop, 2nd crop cycle

Relationships - other crops

P, 1st cycle logM.G.R. = 0.094$\bar{T}$ - 1.175 r= 0.811**
1R, " " " = 0.090$\bar{T}$ - 1.143 r= 0.819**
P, 2nd " " = 0.105$\bar{T}$ - 1.568 r= 0.886**
2R, " " " = 0.116$\bar{T}$ - 1.776 r= 0.843**