AVAILABILITY OF SOIL WATER TO SUGARCANE[1] IN NATAL

By J. N. S. HILL

Introduction

The theoretical aspects of water availability to plants have been covered by Philip (1957) and Gardner (1960), whilst Makkink and van Heemst (1956) and more recently Denmead (1961) have presented supporting experimental evidence. In a preliminary report on water availability in some Natal sugarbelt soils, Hill and Sumner (1964) briefly discussed the concept and presented data to indicate that the quantity of available moisture in certain soils varied with evaporative demand. Since their results were affected by the size of the cane plants, the confined volume of soil, and by advective energy, it remained for quantitative information to be obtained on this concept under field conditions.

In irrigation planning two major factors for consideration are the choice of suitable water duties and irrigation frequencies or periods. Thus with any single water duty, say 170 acres per cusec, there is the choice of applying say applications of 1-inch every 7 days, or one 2-inch application every 14 days. Each particular irrigation period has its own merits and disadvantages. In general, longer periods favour labour utilisation efficiency, but in many cases the condition of the soil dictates the period. Certain soils will not accept large applications of water and run-off becomes a serious problem. On these soils, shorter irrigation periods become essential, and the introduction of a remunerative incentive can encourage good efficiency in operation.

In order to shed further light on this problem, field trials comprising various irrigation treatments were laid down. These treatments were designed to yield quantitative information on water availability to sugarcane in different soils. It was reasoned that such information could be used to evaluate the effects of different irrigation periods on growth and yield of sugarcane. The experiments and techniques used are described below.

Methods

During the period 1963 to 1965, there were five irrigation experiments in operation, four being located on Windermere clay loam, and the fifth on Clansthal sand. The experiments were of the randomised block design with four replications of various irrigation frequency treatments. The treatments themselves consisted of a range of water application levels so designed as to replenish the estimated soil moisture deficit (from Class A pan evaporation) to field capacity. Thus when the predicted soil moisture deficit reached a specified level, then this total amount of water was applied to bring that treatment back to field capacity.

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Owing to uncertainty in consumptive use data for cane with incomplete canopy, no irrigation treatments were started until the measured ground cover was complete. Until that time, all treatments received infrequent but heavy irrigations to relieve severe moisture stress. On two experiments, one on Clansthal sand, the other on Windermere clay loam, crop development studies of the variety N:Co. 382 were carried out. These involved monthly population density counts, weekly canopy development and daily stalk height measurements. The effects of increasing soil moisture deficit could therefore be followed. Some of these crop development data and the harvest results of all these experiments are presented below:

Results

(a) Influence of irrigation frequency on stalk elongation

During the growth of the plant cane crops of N:Co. 382 in two experiments, the treatments were imposed for a period of three months. A comparison between irrigation frequencies of the effects on stalk elongation for the Clansthal sand and Windermere clay loam is shown in figure 1. Growth curves for the highest

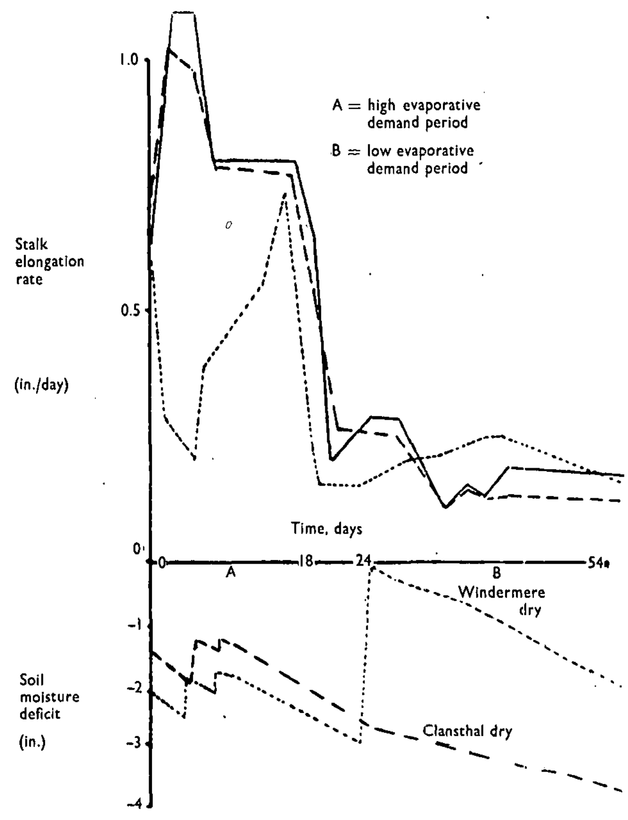

FIGURE 1: Relation between cane growth, evaporative demand, and predicted soil moisture deficit in two Natal soils: solid line represents stalk elongation in both Clansthal sand and Windermere clay loam kept at field capacity; broken line is Clansthal dry, dotted line is Windermere dry.

frequency ($\frac{1}{2}$ inch irrigation when evaporation—E_o—accumulated to $\frac{1}{2}$ inch) and the lowest frequency (3 inches irrigation when E_o accumulated to 3 inches for Windermere soil; 4 inches irrigation when E_o accumulated to 4 inches for Clansthal sand) are presented. As can be seen in figure 1, irrigation frequency has little effect in Clansthal sand but influences stalk elongation in Windermere clay loam markedly during the high evaporative demand period. After the first 18 days when average daily Class A pan evaporation was 0.18 in., conditions became much cooler and evaporative demand (average 0.10 in./day) was reduced until irrigation frequencies lost their effect on stalk elongation.

Stalk elongation measurements were continued on the first ratoon crops, which experienced one of the most severe droughts in the history of the sugarbelt. Thus the total irrigation applications were very similar in all treatments and on both soil types. In figures 2 and 3 the growth pattern of sugarcane under various irrigation frequencies is shown for Clansthal sand and Windermere clay loam respectively. It can be seen that prior to harvest, irrigation frequency has resulted in a wider spread of stalk lengths on Windermere soil (10 inches between $\frac{1}{2}$ and 3 inch frequencies) than on Clansthal sand (6 inches between $\frac{1}{2}$ and 4 inch irrigation frequencies). But, perhaps more important, is the seasonal effect on stalk elongation indicated in these figures. During the high evaporative demand period of January, February and up to the 11th March, 1965, the slopes of the growth curves for various irrigation frequencies are not greatly different for Clansthal sand whereas far greater differences are visible on Windermere clay loam. On both soils, however, growth curves tend to parallel between irrigation frequencies after about mid-March.

The influence of estimated soil moisture deficiency on stalk elongation of sugarcane on these two soils is best illustrated in figures 4 and 5. These figures represent the high evaporative demand period (18th January to 15th March, 1965) when mean Class A pan evaporation was 0.24 in./day. Daily stalk elongation measurements have been differentiated into relative growth rate values (ratio of stalk elongation at any particular soil moisture deficit to that on soil kept close to field capacity by frequent irrigation).

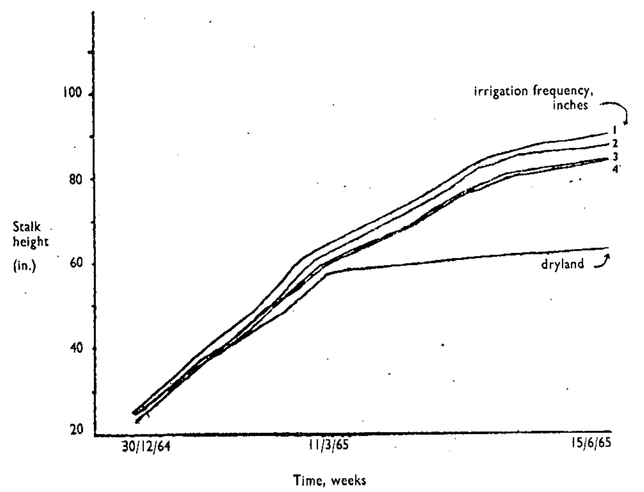

FIGURE 2: Growth pattern of sugarcane in Clansthal sand as influenced by irrigation frequency.

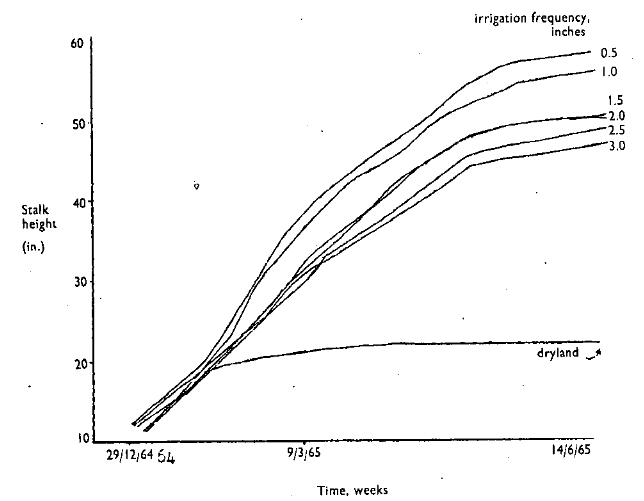

FIGURE 3: Growth pattern of sugarcane in Windermere clay loam as influenced by irrigation frequency.

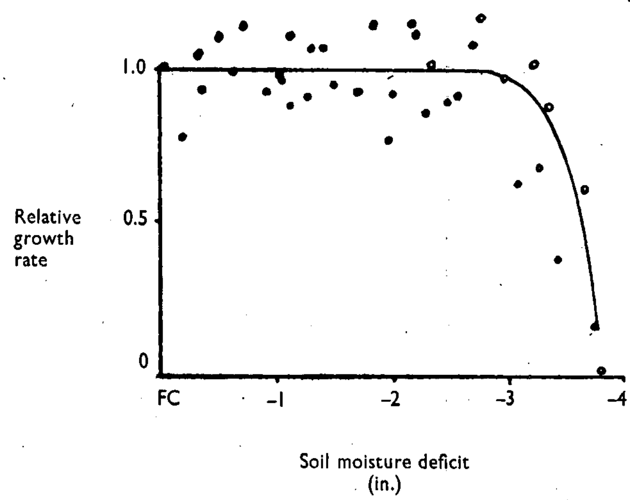

FIGURE 4: Relative growth rate of sugarcane in Clansthal sand.

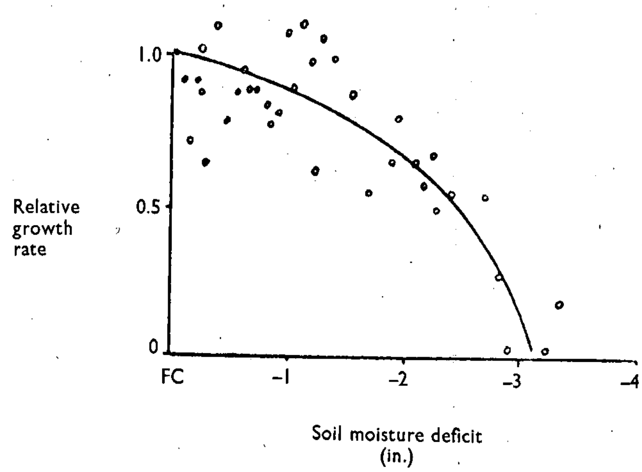

FIGURE 5: Relative growth rate of sugarcane in Windermere clay loam.

These figures show that potential cane growth declines when the estimated moisture deficit in the soil profile is 1 inch for Windermere clay loam and 3 inches for Clansthal sand.

(*b*) *Influence of irrigation frequency on cane yield*

Some of the earliest work on irrigation frequencies was conducted at Tongaat by Dr. T. G. Cleasby. Trials harvested in 1957, 1958 and 1960 (the earliest years being high rainfall seasons) showed that there was a tendency for N:Co.310 to respond to high frequency irrigation on Windermere clay loam. These harvest results are presented in Tables I, II and III.

TABLE I

Response by plant cane N:Co.310 to different irrigation frequencies

*Treatment: irrigation frequency, days	Total irrigation inches	Yield T.C.A.	Response T.C.A.
7	26	57.1	22.2
14	21	49.4	14.5
21	20.5	48.6	13.7
Dryland control	0	34.9	—

* Irrigation treatments consisted of replenishing the soil moisture to field capacity at the intervals noted. Soil moisture deficit was estimated from progressive Symons tank evaporation employing a factor of 0.85 to represent evapotranspiration, whilst irrigation efficiency was taken as 75%
L.S.D. (1%) 10.16 T.C.A.; (5%) 7.07 T.C.A.

TABLE II

Response by first ratoon cane N:Co.310 to different irrigation frequencies

Treatment: irrigation frequency, days	Total irrigation inches	Yield T.C.A.	Response T.C.A.
7	18	43.5	15.7
14	14	41.1	13.3
21	14	42.7	14.9
Dryland control	0	27.8	—

TABLE III

Response by second ratoon cane N:Co.310 to different irrigation frequencies

Irrigation frequency, days	Total irrigation inches	Yield T.C.A.	Response T.C.A.
7	33	56.8	35.6
14	30	50.7	29.5
21	29	47.5	26.3
Dryland	0	21.2	—

Further experiments involved during the period 1963, 1964 and 1965 contained the varieties N.50/211, N:Co.376, N:Co.382 and N:Co.310 in various stages from plant cane until 4th ratoon. Harvest results are presented in Tables IV to VII. Correlation coefficients between stalk length at harvest and yield in tons cane are presented in Table VIII. It can be seen that in general sugarcane responds in tons cane per acre to higher frequency irrigation on Windermere clay loam, whereas no such response is noticeable on Clansthal sand. In terms of response in yield over dryland production, the results of all trials have been "averaged" to produce the data in figure 6. In figure 6 the arbitrary linear subdivision of the x-axis is in terms of average soil suction at the time of irrigation. These intervals could also represent days of evaporation (cycle length) or moisture deficit in the soil profile (inches).

It is quite clear from figure 6 that the potential response to irrigation is far greater on heavy soils than on sand. The reasons for this are that sands accept a higher fraction of natural rainfall (good infiltration properties), support larger root volumes and soil moisture is less readily available to sugarcane in heavy soils during the months of maximum growth. It is also seen in figure 6 that low frequency irrigation (with its advantages) is very efficient on sand. Since these findings project their consequences on irrigation planning, they are discussed as such in the following section.

Discussion and Conclusions

One fact which has emerged from these results is that the potential response to irrigation is greatest on heavy soils. This of course is due to the fact that it is on these soils that drought effects are so severe. This severity of drought is due to several factors. In general, although there are notable exceptions, heavy clay soils have poor infiltration properties and thus rainfall acceptance is reduced, run-off increased. Thus for a start, the cane crop has to thrive on a lower total amount of soil moisture during the season. Secondly, soil moisture in clays is less readily available to sugarcane during periods of high evaporative demand. Thus during the months of maximum growth, stalk elongation is greatly affected by numerous small drought periods.

The question of real importance is whether the potential response, or yield of about 60 tons cane per acre per annum can be achieved under field conditions with irrigation. The experiments suggest that such a potential is more easily reached on sands than on heavy soils. Thus the argument resolves into two parts:

(*a*) *Factors of academic interest*

Soil water is *not* equally available to sugarcane over the range field capacity to the wilting points in all soils and under all climatic conditions. In coastal Natal, during the summer months December to March, stalk elongation is reduced on heavy soils after relatively small deficits of moisture have occurred

TABLE IV

Response by plant cane N:Co.382 to various irrigation frequencies on two Natal Soils

Treatment (Irrigation frequency)	Total irrigation (inches)		Yield, tons cane/acre/annum	
			Clansthal sand	Windermere clay loam
Dryland	Clansthal Nil	Windermere Nil	32.3	16.9
v. high	6.5	14.0	38.8	36.8
high	4.0	14.0	39.3	30.0
medium	4.0	10.0	37.6	25.2
low	4.0	9.0	35.2	22.1

Clansthal L.S.D. (1%) 10.7 T.C.A.; (5%) 7.5 T.C.A.
Windermere L.S.D. (1%) 8.9 T.C.A.; (5%) 6.5 T.C.A.

TABLE V

Response by N.50/211— and N:Co.376 first ratoons to various irrigation frequencies on Windermere clay loam

Irrigation frequency	Total irrigation (inches)		Yield, tons cane/acre/annum	
			N.50/211	N:Co.376
Dryland	N.50/211 Nil	N:Co.376 Nil	17.0	26.8
v. high	13.0	15.0	43.1	47.7
high	13.0	15.0	43.7	43.4
medium	13.0	14.0	34.3	37.4
low	9.0	—	35.1	—

TABLE VI

Response by 1st ratoon N:Co.382 to various irrigation frequencies on two Natal soils

Irrigation frequency (inches)	Total irrigation (inches)		Yield, tons cane/acre/annum	
	Clansthal	Windermere	Clansthal sand	Windermere clay loam
0.5	24.0	24.0	—	45.1
1.0	—	24.0	53.3	46.1
1.5	—	23.0	—	46.7
2.0	24.0	24.0	52.1	41.9
2.5	—	22.0	—	42.9
3.0	24.0	23.0	54.3	39.0
4.0	24.0	—	51.3	—
dryland	Nil	Nil	33.6	11.2

Clansthal L.S.D. (1%) 11.7 T.C.A.: (5%) 8.2 T.C.A.
Windermere L.S.D. (1%) 11.6 T.C.A.: (5%) 8.5 T.C.A.

TABLE VII

Response by 4th ratoon N:Co.310 to various irrigation frequencies on Windermere clay loam

Irrigation frequency (inches)	Total irrigation (inches)	Yield tons/cane/ acre/annum
dryland	Nil	6.0
1.0	20.0	26.0
2.0	20.0	21.4
3.0	20.0	21.9

L.S.D. (1%) 6.8 T.C.A.: (5%) 4.9 T.C.A.

TABLE VIII

Correlation coefficients between stalk length at harvest and yield in irrigation experiments

Variety	Stage	Coefficient
N:Co.376	1st ratoon	0.94
N:Co.310	4th ratoon	0.98
N:Co.382	1st ratoon	0.94
N:Co.382	1st ratoon	0.81
N.50/211	2nd ratoon	0.95

in the soil profile. On such soils therefore, potential yields can only be assured by low water duties and high irrigation frequencies.

On sands, such a decline in stalk elongation is not as noticeable and it is believed that this is explicable in terms of amount and availability of soil moisture in the root zone. Thus on these soils, close to potential yields can be achieved with higher water duties and much lower irrigation frequencies.

(*b*) *Factors of economic importance*

The attainment of potential crop yields under irrigation, and indeed the entire concept of irrigation planning with water duty considerations, etc., is deeply involved with economics. Thus the water duty necessary to produce potential crop yields might well be economical on one soil but not on another.

It is believed that from these results it is possible to be categorical only as concerns irrigation frequencies (or periods). The economics of the water duty question remain to be solved, although certain suggestions can be put forward. If the yield results in Table VI are studied, it will be seen that, although sugarcane responds to high frequency irrigation on Windermere clay loam, this response is not great. When it is remembered that these results were obtained during one of the driest seasons ever recorded, then

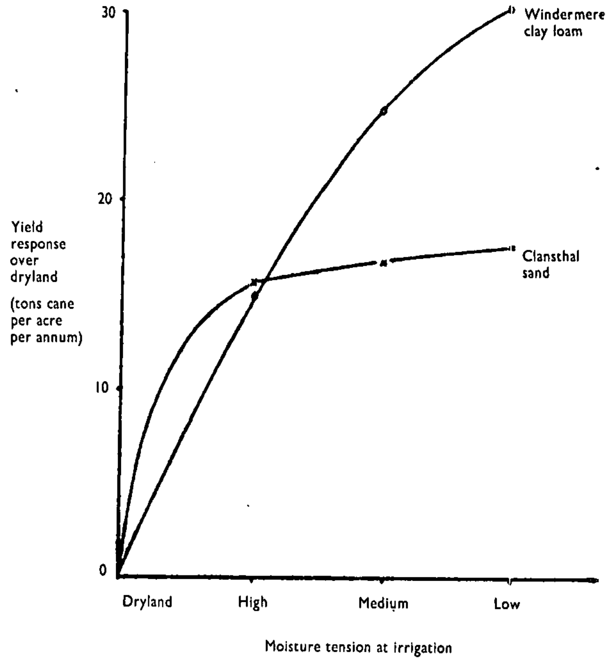

FIGURE 6: Response by sugarcane to irrigation in two soils when the moisture tension at time of water application varies.

such a difference can be seen in its true perspective. Therefore it is suggested that on sands, low irrigation frequencies are suitable. Applications of 2 to 3 inches of water will be as effective in their own cycles as would be more frequent irrigations of 1 inch. On heavy soils, it is believed that any application up to about 2 inches, within its own cycle, is suitable. On these soils, however, physical properties often dictate the application level and irrigations of 1 inch are probably optimum.

Water duties may be extended on sands to take full advantage of the large root-zone reservoir and close to potential yields should be obtainable when other factors are not limiting. On heavy soils it is believed that lower water duties are advisable but, in fact, suitable experimental evidence is not yet available to substantiate such a remark. In conclusion, an experimental technique is proposed that should shed further light on this problem. An irrigation experiment should have treatments based directly on water duties. Once it is decided as to the application level which the soil will safely hold, then different treatments simply involve the application on different cycles. Each cycle should furthermore be split for a climatic effect such that if say, one treatment involves irrigating 1 inch every 8 days commencing on the 1st of a month, its conjugate treatment also applies 1 inch every 8 days but commences on the 4th of the month. In this way, for each treatment, a climatic or weather effect can be taken out in the same season. Such an experiment is already under way at Tongaat and results are awaited with interest.

Summary

Experiments conducted to investigate the availability of moisture to sugarcane in different soils have revealed that cane responds to high frequency irri-

gation on clayey soils but not on sands. This finding influences the choice of irrigation application levels and periods. Heavier, less frequent irrigations are suitable for sands whereas there is a tendency for lighter, more frequent irrigations to be better on heavy soils.

Water duties may be extended on sands whilst on heavy soils information regarding the economics of different water duties is lacking. An experimental technique has been proposed for yielding information on the water duty question in irrigation experiments.

References

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Mr. van Schalkwyk: Contrary to previously held opinions, Mr. Hill now tells us that sandy soils require large amounts of water at long intervals.

Mr. Hill: The main reason for this is that on heavy soils the available moisture measured by the laboratory technique can be very much higher than that measured on sandy soils. If the correct technique is used, however, that is soil bulk density effects are taken into consideration, then it will be found that there are no great differences between total available moisture values for different soil types. Thus sandy soils hold much the same amount of moisture for plants as do clay loams per unit depth. This is where relative availability of soil moisture comes in. All the available moisture measured in a sand is easily withdrawn by plants, whereas only a fraction of the total available moisture measured in heavy soils is easily taken up under hot, windy conditions.

Mr. Landsberg: I would like to mention the important factor of rooting depth in different soils. Doesn't Mr. Hill believe that his yield and stalk elongation rate differences measured on different soils can be explained in terms of different rooting depths?

Mr. Hill: Rooting depth differences undoubtedly play an important part in the overall concept of irrigation. However, the results reported in this paper seemed to indicate that even that moisture held within the limits imposed by rooting depth was differently available, depending on soil type. For example, in the heavy soil the rooting depth of sugarcane was seen to be approximately 2 feet. Yet this soil which held $1\frac{1}{2}$ inches of available moisture per foot of soil, that is about 3 inches of total available moisture, could not support the potential growth rate when only as little as 1 inch of water had been removed.

Dr. Thompson: I would like to mention the ratio of potential evapotranspiration to Class A pan evaporation for fully canopied sugarcane for a 24-day period last October. These quantities were measured daily and the mean ratio was found to be 0.98, and this includes the effects of very stong advection on several days.

In the succeeding first ratoon crop the ratio had increased to approximately 1.0 by the time the vertical ground cover was fifty per cent. It is therefore apparent that, because of sun angle, effective canopy must always be in excess of vertical ground cover.

Secondly, I think you will agree that the decision to go for a low frequency of irrigation on a sandy soil will depend on the slope of the response curve of the type shown in Figure 6. Actual increased yield must always be measured against the saving in labour owing to less frequent irrigation.

Mr. Halse: By increasing the frequency more capital costs are also incurred.

Mr. Hill: Not necessarily. If one is dealing with a dynamic scheme—that is one already designed and operating—no extra capital costs are involved. If, however, one were to design a scheme with this concept in mind, water duties might be altered and this could incur additional capital costs.

Mr. du Toit: From Figure 5 it would appear that growth of cane on Windermere soil could actually increase between field capacity and a deficit of one inch. Were any such measurements recorded?

Mr. Hill: On certain days we found that cane in Windermere and Clansthal soils at relatively small moisture deficits did exceed in stalk elongation, cane growing in plots kept as close as possible to field capacity. This is not easy to explain. I can only suggest that photosynthesis and the production of growth substances in the plant is less susceptible to water stress than is actual production of dry matter as reflected by stalk elongation. Thus on days of high evaporative demand there is a net build up of photosynthetic products which are not used up in actual growth due to loss of turgidity in the plant cells. If the following day is of a slightly lower evaporative demand, then on this day those plants containing a carry-over of growth substances actually grow more than do plants which had used up all their growth substances the day of production.

Mr. Browne: In places like the Eastern Transvaal where daily evaporation sometimes exceeds 0.40 inches, can we apply some factor to reduce the 1:1 ratio as an estimate of consumptive use?

Mr. Hill: I know of no evidence which puts an upper limit on the transpiration rate of sugarcane. However, I have seen data on maize grown in the United States which puts the maximum transpiration rate for this crop at 26 parts per day. This of course implies that there is a maximum diffusion pressure deficit which can be developed in the leaves. There are several reports in the literature concerning this maximum D.P.D. and, again for corn, I think I have noticed a value of about 100 bars. Whether or not we can use this value for sugar cane I am not sure.

Mr. Browne: Are investigations being pursued anywhere to determine this value?

Mr. Hill: I personally do not have the equipment to do so, but perhaps Dr. Thompson can help us.

Dr. Thompson: We are following it up by looking at the two things which can effect the ratio, namely the relative advective effects in different areas and the relative degrees of physiological control of transpiration.

Mr. Collings: Mr. Hill mentioned the possible increase and decrease in capital investment and it was said we could put 2 inches on a sandy soil instead of 1 inch. If you apply 1 inch on a seven day cycle or 2 inches on a fourteen day cycle you do not change your capital investment or equipment. However, 1 inch applied on a 14 day cycle means a different water duty and a reduction in field equipment per unit area. Your mains and pumping unit, however, do not necessarily change in proportion.

Mr. van Schalkwyk: It is the excess wear on equipment through constant movement that is costly, not the capital expenditure.