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Effects of nitrogen fertilizer, plant population and irrigation on sugar beet

III. Water consumption

By A. P. DRAYCOTT and M. J. DURRANT

Broom's Barn Experimental Station, Higham, Bury St Edmunds, Suffolk

SUMMARY

A neutron moderation meter was used to measure soil moisture 0–4 feet deep in plots of sugar beet carrying two plant populations (8800 and 54000 plants/acre), each with and without irrigation. Recordings began in April or May in each of three years (1967–9) after sowing the crop and continued at 1 or 2-week intervals until harvest in October.

The measured soil moisture deficits were very similar to potential deficits calculated from meteorological measurements. This indicates that the crop could extract the water needed for transpiration from the soil even when the deficits were quite large (more than 5 in in 1967), which probably explains the small response to irrigation by sugar beet in England.

When the soil moisture deficit increased rapidly early during the season (1967), the crop extracted water from the soil by exhausting the available water from progressively deeper horizons, whereas when the deficit increased rapidly late during the season (1969) water was still being extracted from all horizons until harvest. Both decreasing the plant population and irrigating decreased the amount of water used from depth in the profile every year.

The total amount of water used (evaporation plus transpiration), on average, from soil reserves and rainfall, was 12·2 in by the small population and 13·4 in by the large population. When irrigated, the consumption increased to 14·2 and 15·4 in. respectively. The difference in usage between populations was almost entirely from the difference in leaf cover early during the season. The water consumption in 1968, when the summer was wet, was only two-thirds of that in 1967 and 1969 when the summers were drier.

INTRODUCTION

Experiments in England testing irrigation for sugar beet (Penman, 1952, 1962; Price & Harvey, 1962) show that, relative to other crops, increases in sugar yield are usually small, though in some years economically significant (about one in three at Woburn (Penman, 1962). The responses in 1965–9 described in Part I show that there was a small increase in yield in two out of five years at Broom's Barn.

Penman (1962) suggested that the small response is a result of the deep and efficient root system of sugar beet, which allows the crop to draw on the reserve of moisture at depth when growth of shallow-rooted crops is restricted by water shortage. To investigate the validity of this suggestion, the extraction of water from the soil profile by the crop was measured in the experiments during 1967–9.

EXPERIMENTAL

The field experiments were described in Part I (Draycott & Webb, 1971). Soil moisture was measured in plots of the smallest (8800 plants/acre) and largest (54000 plants/acre) populations, with and without irrigation. Access tubes for the moisture probe were inserted after sowing and before singling the crop. Two tubes were used in each of the four treatments so that duplicate measurements could be made each week (in 1969) or fortnight (in 1967 and 1968).

The meter, probe and principles of the method were described by Long & French (1967). Their techniques of using the instrument in the field were adopted, making measurements at 2 in intervals down to 6 in and at 4 in intervals down to 4 ft.

Daily rainfall, solar radiation, sunshine hours,

wind speed, maximum and minimum temperature and humidity were measured within half a mile of the experiments. The percentage leaf cover was also estimated periodically and the soil moisture deficit calculated by the method described by Penman (1952).

RESULTS AND DISCUSSION

Measured soil-moisture deficit

Figure 1 shows the cumulative soil-moisture deficit in the top 4 feet of soil each year for the two plant populations, with and without irrigation,
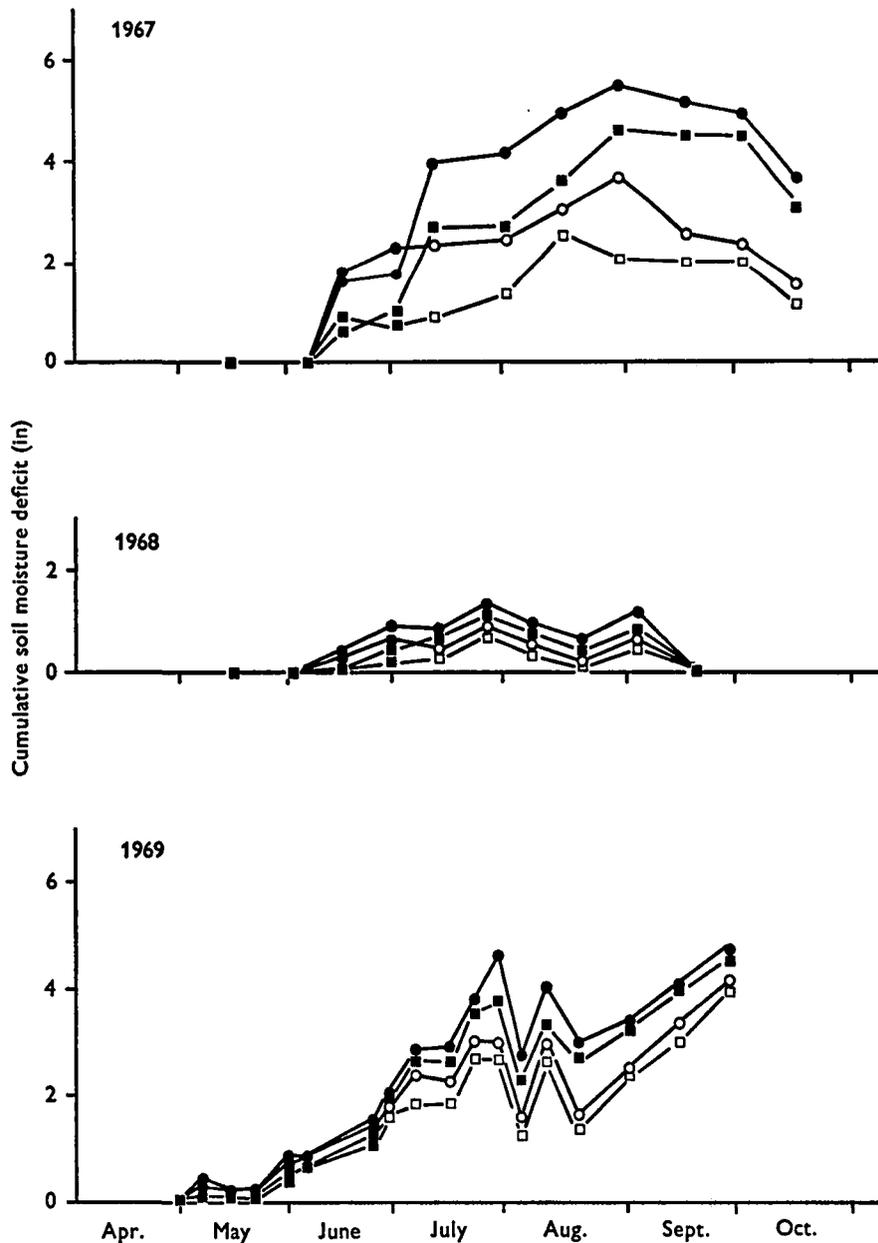

Fig. 1. Measured cumulative soil moisture deficits (0–4 ft), 1967–9. ●, 54 000 plants/acre; ■, 8800 plants/acre; ○, 54 000 plants/acre irrigated; □, 8800 plants/acre irrigated.

assuming field capacity when the measurements began (Long & French, 1967).

In 1967 the rainfall exceeded evaporation and transpiration (Draycott & Webb, 1971) from the beginning of measurements until June. Several hot dry periods caused the crop to wilt during July and August and the soil-moisture deficits increased to a maximum of 5·6 in (large population) and 4·6 in (small population). Early during the summer the deficit with large population increased faster than with the small population but later changes in the deficits for the two populations were similar. During autumn, rainfall exceeded the need of the crop and the excess decreased the deficit considerably.

In 1968 the measured soil moisture deficits never exceeded 1·5 in for the summer was much wetter than average. The soil in irrigated plots returned to field capacity during August and in all plots during September, when 4·6 in rain fell in one week. The deficits followed a different pattern in 1969, increasing throughout the months May to October, except for two short periods during August, and were still increasing quite rapidly at harvest.

Irrigation decreased the deficits each year but by less than the amount applied – Long & French (1967) reported a similar result at Rothamsted. The reason for this apparent increased usage of water by irrigated sugar beet is being investigated in further experiments at Broom's Barn.

Potential transpiration and measured deficit

Potential transpiration was calculated at weekly intervals each year from meteorological data by the method described by Penman (1952). Fig. 2 shows the relationship between cumulative potential transpiration (ΣE_T) and the sum of rainfall, irrigation, and measured soil moisture deficit in the top 4 ft of soil (*Est.E.*).

In all three years ΣE_T was about 2 in before a deficit began to accumulate in the soil. The crop had a negligible leaf cover during April and water losses were almost entirely by evaporation from bare soil. In May the two plant populations transpired different quantities of water because of differences in leaf cover and, once established, this difference between the two populations persisted throughout the season. However, when the leaf cover was complete (e.g. large population after 1 June every year) a linear relationship was established between ΣE_T and *Est.E.* In 1967 the apparent decrease in water usage by the large population without irrigation during August and September could be accounted for by increased water usage from below the depth of measurement.

The results in 1967 and 1969 suggest that the sugar beet extracted water very efficiently from the soil, because the slope of the line relating ΣE_T to *Est.E.* was very nearly equal to one, even without
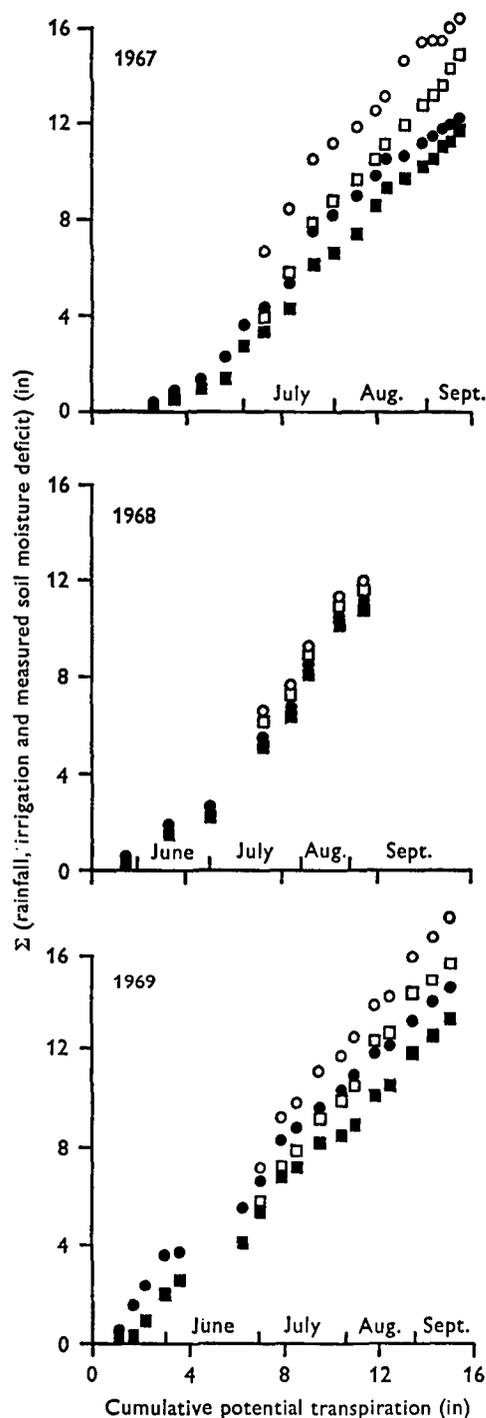

Fig. 2. Cumulative potential transpiration and the sum of rainfall, irrigation and measured soil moisture deficit, 1967–9. ●, 54000 plants/acre; ■, 8800 plants/acre; ○, 54000 plants/acre irrigated; □, 8800 plants/acre irrigated.

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irrigation. This probably explains why the crop is relatively unresponsive to irrigation.

Water extraction from the soil profile

Figure 3 shows the maximum amount of water removed from each depth by the plant populations, with and without irrigation. Measurements in the surface 12 in are not included as they were affected by rainfall and irrigation. In 1968 rain percolated below 12 in at the beginning of August and measurements after then have not been included. Similarly, no measurements for irrigated plots are given for 1968, because some irrigation water or rain percolated below 12 in in July.

The results for 1967 and 1969 show that irrigation decreased the amount of water removed by both populations from below 12 in. It will be shown later (Table 1) that the irrigation increased the total water-usage by the crop, thus irrigation must have greatly increased the amount of water used from the surface soil. As plant nutrients are most concentrated in the surface soil, this may partially
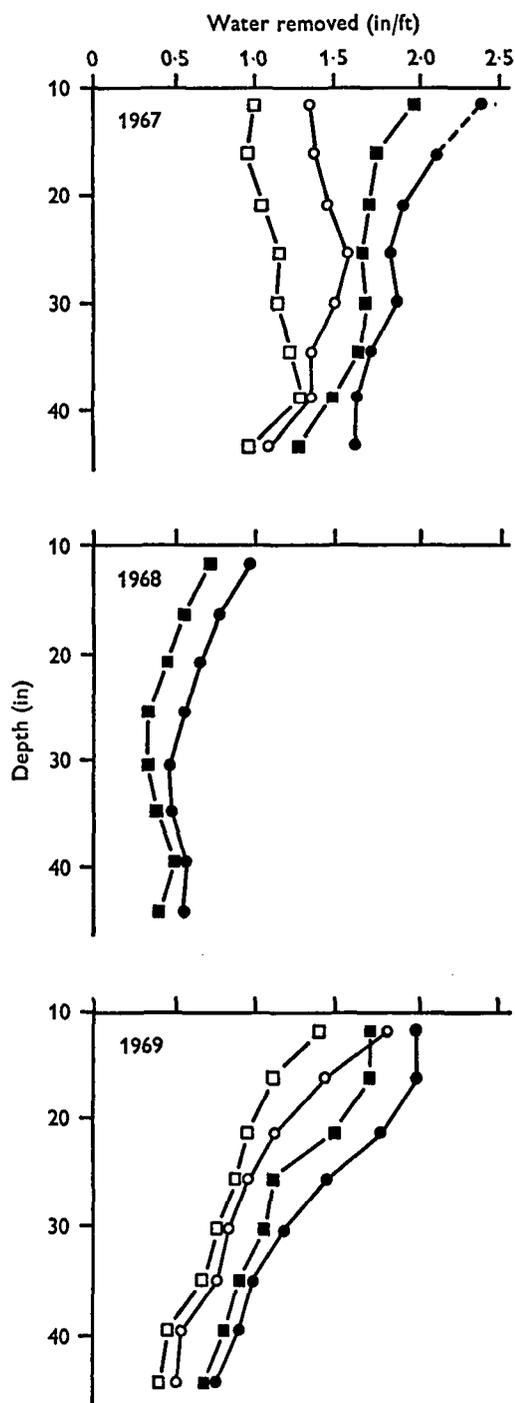
Fig. 3. Maximum amount of water removed from each soil depth, 1967–9. ●, 54 000 plants/acre; ■, 8800 plants/acre; ○, 54 000 plants/acre irrigated; □, 8800 plants/acre irrigated.
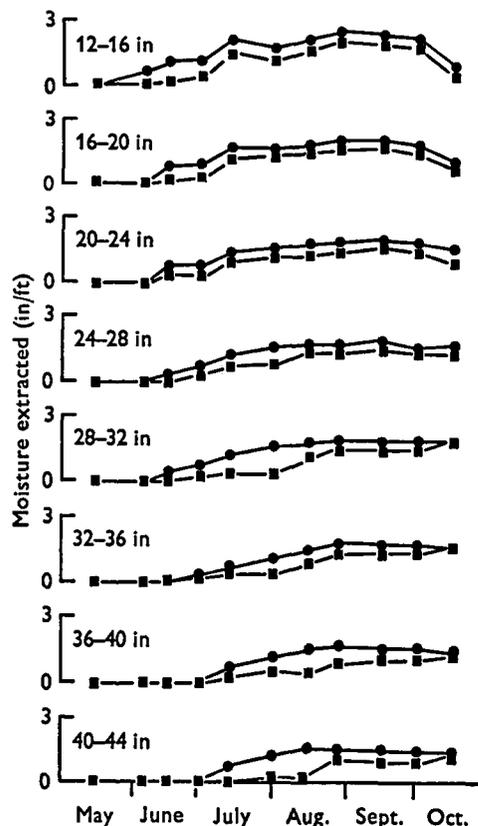

Fig. 4. Total amount of water extracted from each soil depth in 1967. ●, 54 000 plants/acre; ■, 8800 plants/acre.

explain the increased uptake of nutrients by the irrigated crop.

The large population removed more water, from each depth in every year, than the small population. This suggests that the roots of plants in the large population ramified the soil more thoroughly at all depths than those of the small population. It was not clear whether they did this more near the surface or, as suggested by Harris (1970), at depth.

In 1967 (the year when the soil moisture deficit rapidly increased in June) the crop extracted water from the soil by exhausting the available water from progressively deeper horizons. This did not happen in 1968, as rain rewetted the soil at depth; nor in 1969, when water was still being extracted from most horizons until harvest. This probably explains the larger response to irrigation in 1967 (6·1 cwt/acre sugar) than in 1969 (2·2 cwt/acre), when the maximum soil moisture deficits in the two years were somewhat similar.

Figure 4 shows the pattern of water extraction from each of eight horizons in 1967 by the two plant populations, without irrigation. Early in the season soil water was extracted from increasing depth with time, and this is interpreted as gradual extension and ramification of the soil by the root system. Roots of the large population penetrated deeper and extracted water faster than those of the small population. During the summer the amount of water extracted from each horizon increased to a maximum, and

the large population always reached the maximum before the small population. These maximum values for each horizon seemed to represent the total amount of water the crop could use – an *in situ* measure of available water capacity of the soil.

Total water consumption

Table 1 shows the total quantity of water evaporated and transpired each year by the two plant populations, with and without irrigation. The period of measurement each year was from sowing until harvest. The results represent the total amount of water lost from the soil during this period plus rainfall and, where appropriate, irrigation. The total loss from the soil was the sum of the losses from the top 4 ft of soil (measured) and from below 4 ft (extrapolated). Table 1 shows that the amounts of water used from below 4 ft were usually small and with irrigation were negligible.

The small plant population without irrigation used a total of 12·2 in of water and the large plant population 13·4 in, on average. When irrigated, the use increased to 14·2 for small and 15·4 in for large populations. This effect of plant population, although small, was consistent each year. Considerably less water was used by both populations in 1968, when the summer was dull and wetter than average, than in 1967 and 1969, when the summers were relatively dry and sunny.

Table 1 also shows the consumption of water

Table 1. *Water consumption by two plant populations with and without irrigation, 1967–9*

Year	Period	8800 plants/acre		54000 plants/acre	
		Without irrigation	With irrigation	Without irrigation	With irrigation
Total water consumption/acre (in)					
1967	10 May–17 Oct.	12·8	14·9	13·8	16·5
1968	21 May–3 Oct.	10·7	11·7	11·2	12·0
1969	24 Apr.–26 Sept.	13·1	15·9	15·2	17·8
Mean		12·2	14·2	13·4	15·4
Total water consumption/plant (gallons)					
1967	10 May–17 Oct.	42·5	49·5	5·6	6·8
1968	21 May–3 Oct.	35·5	38·8	4·6	4·9
1969	24 Apr.–26 Sept.	43·5	52·8	6·2	7·3
Mean		40·5	47·1	5·5	6·3
Water removed from the soil, 0–4 ft (in)					
1967	10 May–29 Sept.	4·1	1·7	5·0	3·4
1968	21 May–26 July	0·9	0·5	1·0	0·5
1969	24 Apr.–26 Sept.	4·7	3·9	4·8	4·4
Mean		3·2	2·0	3·6	2·8
Water removed from the soil, below 4 ft (in)					
1967	10 May–29 Sept.	1·2	0·1	1·6	0·1
1968	21 May–26 July	0·1	0·0	0·2	0·0
1969	24 Apr.–26 Sept.	0·2	0·1	0·9	0·4
Mean		0·5	0·1	0·9	0·2

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calculated for a single plant. The large plants used far more water than the small ones – on average, about eight times as much. This probably partially explains the difference in nutrient status of the crop grown in different plant populations. All the water-soluble elements measured usually became less concentrated with increases in plant population, i.e. with the amount of water used by each plant, whereas concentration of the relatively insoluble element phosphorus was unchanged by differences in plant population (Draycott & Durrant, 1971).

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