SOIL MOISTURE EXTRACTION PATTERNS FROM IRRIGATED AND DRYLAND ARABLE CROPS IN CANTERBURY

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ABSTRACT

Soil moisture extraction patterns as measured by neutron probe are reported for barley, wheat, field pea, sugar beet and potato crops grown at Lincoln over a number of years. The barley was grown as a dryland crop and the wheat, peas and sugar beet were irrigated to provide sufficient soil moisture for growth. The potatoes were grown under three irrigation regimes; full, half, and none.

If necessary, substantial amounts of water were extracted from depths of at least a metre. Where irrigation was applied, extraction tended to be confined to the upper profile.

Barley extracted a substantial proportion of its water from near the top of the profile while sugar beet and unirrigated potatoes extracted water evenly throughout the profile. The results for sugar beet suggest a substantial extraction of water from deeper than a metre.

Frequent small irrigations, which confine extraction to surface layers where nutrients are more concentrated, are likely to be more effective than infrequent large irrigations.

Additional Key Words: *Neutron probe, extraction depth, wheat, barley, field peas, potatoes, sugar beet, water budgets, irrigation scheduling.*

INTRODUCTION

The purpose of water budgeting for irrigation scheduling is to minimise crop loss from drought. Water should be applied before the lack of soil moisture limits crop growth (Jamieson *et al.*, 1984a). The soil moisture deficit at which crop growth becomes limited depends largely on the available water holding capacity (AWC) of the soil. AWC is a function both of the physical properties of the soils and the abilities of crops to extract the water. Crop extraction depends on the distribution and depth of roots and will vary with crop type. For instance, Abdul-Jabbar *et al.* (1982) found lucerne roots to depths of at least 1.5 m but this increased with irrigation. Jodari-Karimi *et al.* (1983), in an experiment with lucerne grown in 1.2 m deep pots, found root distribution was affected by depth of irrigation. Hall and Jones (1983) found substantial changes of soil moisture under grasslands in Britain to depths of 1 m but the amount extracted was greatly affected by the physical properties of the soil. Hayman and Stocker (1982) found that pasture extracted most of its water from the upper profile but lucerne extracted equal amounts of water from all the depths measured. Hence both crop type and agronomic treatment can affect root distributions and hence AWC.

A water balance for a soil - crop combination can be written as follows:

$$\text{Water use} = \text{Evapotranspiration} + \text{Drainage}$$
$$= \text{Rainfall} + \text{Irrigation} - \text{Runoff} - \Delta S$$

where ΔS is the change in soil moisture storage (S).

Rainfall, irrigation and S can be measured directly and, on flat terrain, runoff can be assumed to be zero. If S is measured as a function of depth then the contribution of each depth interval to water use can be calculated. Drainage is a loss of water to the system and can be a substantial fraction of water use in irrigated cropping (Jamieson *et al.*, 1984a).

Root distributions are notoriously difficult and tedious to measure (Abdul-Jabbar *et al.*, 1982). However, the physical consequences of these distributions, changes in soil moisture content with time and depth in relation to irrigation and rainfall, are not (Hayman and Stocker, 1982; Jamieson *et al.*, 1984a). The purpose of this paper is to report on soil moisture extraction patterns by a variety of crops, both irrigated and dryland, grown in one soil at Lincoln, and to discuss the significance of the results for irrigation scheduling.

MATERIALS AND METHODS

Crops

All the crops were grown between 1979 and 1984 in a 5 ha block of Templeton silt loam soil on the Crop Research Division farm at Lincoln. Soil physical properties are given by Wilson *et al.* (1984). The crops were:

Barley, cv. Zephyr was sown 28 September 1979 and harvested mid-January 1980. The crop was not irrigated. Further details are given in Jamieson (1982).

Sugar beet, cv. Vytomo were sown 3 October 1980 and harvested late May 1981. The crop was irrigated twice with 50 mm applications on 16 January and 20 February 1981. Further details are given by Piyawongsomboon (1981).

Potatoes, cv. Rua, were planted 23 October 1981 and harvested late April 1982. There were three irrigation treatments; full irrigation (FI), i.e. complete replacement of the deficit that occurred in the previous week, half irrigation (HI), i.e. half of that applied to the previous

TABLE 1: Neutron probe measurement details.

Experiment	No. of treatments	No. of tubes per treatment	Tube depth (m)
Barley 1979	1 (dryland)	8	1.0
Sugar beet 1980	1 (irrigated)	5	1.0
Potatoes 1981	3 (irrigation)	3	1.0
Wheat 1984	2 (cultivar)	4	1.6
Field peas 1984	2 (cultivar)	4	1.6

treatment each week, and no irrigation (NI). The last irrigation was applied on 10 March 1982. Further details are given in Jamieson (1985).

Winter wheat, cv.s Rongotea and Avalon were sown 4 May 1984 and harvested mid-January 1985. The crops were irrigated 3 times, with 30 mm on 17 October 1984, 60 mm on 30 October 1984, and 60 mm on 5 December 1984. These were intensively managed, with 250 kg/ha superphosphate incorporated before sowing and 150 kg N/ha applied on 22 August. Disease and weed control were good.

Field peas, cv.s Rovar (fully leafed) and Impulse (semileafless) were sown 12 September 1984 and harvested mid-January 1985. The crops were irrigated twice, with 60 mm on 25 October and 130 mm on 12 December. Superphosphate at 125 kg/ha was incorporated before sowing.

Soil Moisture and Water Use

Volumetric soil moisture was measured at approximately weekly intervals with a neutron probe at 20 cm depth intervals centred from 30 cm down to depths centred at either 90 cm or 150 cm. Details are given in Table 1. Moisture in the upper 20 cm was measured gravimetrically and corrected for bulk density. These data were used together with rainfall and irrigation amounts to calculate crop water use by the water balance method. Drainage losses are likely to have been small in these experiments and have been neglected.

Depth of Extraction

Depth of extraction was determined using the method of Gregory *et al.* (1978). As the roots grow downward into the soil they extract water from progressively deeper layers. As they intrude into a layer and begin to extract water the moisture content of that layer will change more rapidly than before. Discontinuities of moisture content with time identify the time the roots reach a layer. This method is simple for deeper layers or for period without rain or irrigation. However, changes in moisture extraction can be masked by heavy rain or irrigation, particularly in surface layers. Logically, extraction cannot begin from deeper layers before it starts at shallower layers so account must be taken of the overall pattern and inputs of water in deciding when extraction begins in any layer.

RESULTS AND DISCUSSION

Weather

Rainfall and potential evapotranspiration (Penman, 1948) data for all the experiments are given in Table 2, together with 10 year means. In all experiments except those in 1984, potential evapotranspiration was close to the 10 year mean. Potential evapotranspiration in 1984 was 150 mm higher than average for the wheat and 109 mm higher than average for the peas. The barley crop in 1979 received average rainfall. Rainfall was between 60 and 70% of average in all the other experiments.

More important as a measure of drought is the ratio of rainfall to potential evapotranspiration. This varied from a high of 50% for the barley crop to a low of 25% for the potatoes and the peas (Table 2).

Extraction depth

Suitable data for the estimation of extraction depth, unaffected by heavy rain or irrigation, was available from the barley, unirrigated potatoes, and sugar beet crops. The method is illustrated on plots of soil moisture with time at various depths in Figures 1, 2 and 3. In all cases extraction eventually proceeded to the deepest level measured (90 cm). In the barley this occurred quite late, when the crop was nearing maturity. However, in the sugar beet and potato experiments, extraction at 90 cm occurred well before maturity and it is likely that extraction proceeded to greater depths. In both these crops a substantial proportion (29%

TABLE 2: Seasonal rainfall, potential evapotranspiration and their ratio for all the experiments.

Crop	Growing period	Rain	Potential evapotranspiration	Ratio (%)
Barley	Sep 1979- Dec 1979	224 (229)	461 (478)	49 (48)
Sugar beet	Oct 1980- May 1981	323 (459)	882 (907)	37 (51)
Potatoes	Oct 1981- Mar 1982	211 (344)	810 (790)	26 (44)
Wheat	May 1984- Jan 1985	376 (582)	963 (813)	39 (72)
Peas	Sep 1984- Jan 1985)	205 (293)	747 (638)	27 (46)

Values in parentheses are 10 year means.

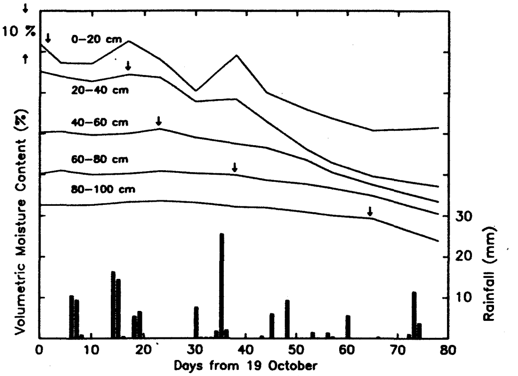

Figure 1: **Changes in soil moisture content for five layers under a barley crop in 1979 showing times of intrusion of roots into each layer. Rainfall events are shown in the histogram. The moisture content curves are displaced vertically for clarity.**

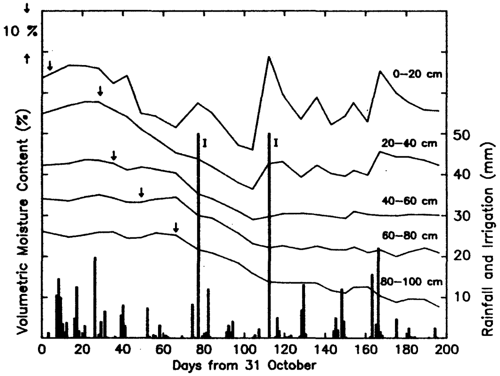

Figure 2: **Changes in soil moisture content for five layers under a sugar beet crop in 1980-81 showing times of intrusion of roots into each layer. Rainfall and irrigation (marked I) events are shown in the histogram. The moisture content curves are displaced vertically for clarity.**

TABLE 3: Net seasonal soil moisture change (mm) in each layer between first and last measurements.

	Layer (cm)								
Crop and Interval	0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	Rain + Irrigation
Barley 15 October — 31 December	41	56	34	20	17	-	-	-	142
Sugar beet 31 October — 15 May	16	25	24	26	37	-	-	-	377
Potatoes (NI) 23 November — 29 March	29	26	18	27	29	-	-	-	72
Potatoes (HI) 23 November — 29 March	20	23	10	8	21	-	-	-	240
Potatoes (FI) 23 November — 29 March	14	9	3	2	9	-	-	-	419
Avalon wheat 12 September — 28 January	27	18	12	16	17	15	7	3	400
Rongotea wheat 12 September — 28 January	22	14	10	13	13	8	4	2	400
Whero peas 12 October — 28 January	26	17	9	10	9	6	3	3	312
Impulse peas 12 October — 28 January	20	16	8	6	7	5	3	4	312

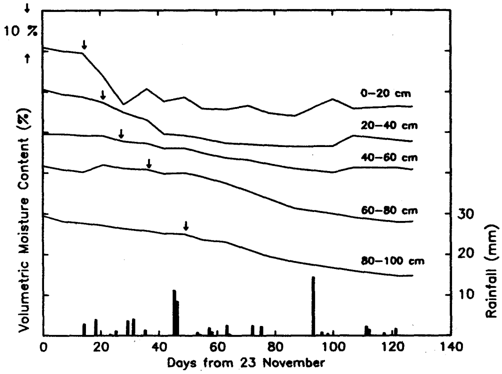

Figure 3: Changes in soil moisture content for five layers under a dryland potato crop in 1981-82 showing times of intrusion of roots into each layer. Rainfall events are shown in the histogram. The moisture content curves are displaced vertically for clarity.

and 23% respectively) of the net seasonal soil moisture change was in the deepest layer (Table 3).

Figure 2, for sugar beet, has some interesting features. After the second irrigation was applied, extraction from the deeper layers almost ceased although it began again from the deepest layer about three weeks later. Clearly crops will extract water from where it is most easily available, in this case the upper layers. Also, once extraction had begun from the deepest layer, the rate of extraction was as rapid as for any other layer which suggests that a substantial amount of water was extracted from below the measured profile.

The largest net seasonal soil moisture changes under the barley were in the upper three layers but net seasonal soil moisture changes under the sugar beet and unirrigated potatoes were fairly similar down the profile (Table 3). For the irrigated potatoes, the largest changes in soil moisture were in the upper two layers (Table 3). Extraction of water from the upper layers is necessarily larger than the net moisture change since rainfall and irrigation water enter the soil at the surface.

The influence of the irrigation treatments on net seasonal soil moisture changes for the potatoes is illustrated in Figure 4. These changes were smaller as more irrigation was applied. There appears to have been a restriction to water extraction at the 50 cm level, probably caused by the presence of a pan. Soil moisture changes in the deepest level in all treatments were similar to those in the upper layer, indicating that the pan did not impede root penetration.

In the wheat crops, where more than 75% of the water use was from rain and irrigation rather than from stored water (Table 4), the largest moisture change was in the surface layer, with similar net seasonal moisture changes down to the 110 cm layer for Avalon and the 90 cm layer for Rongotea. The greater total water use by Avalon (Table 4) reflects its later maturity and later senescence.

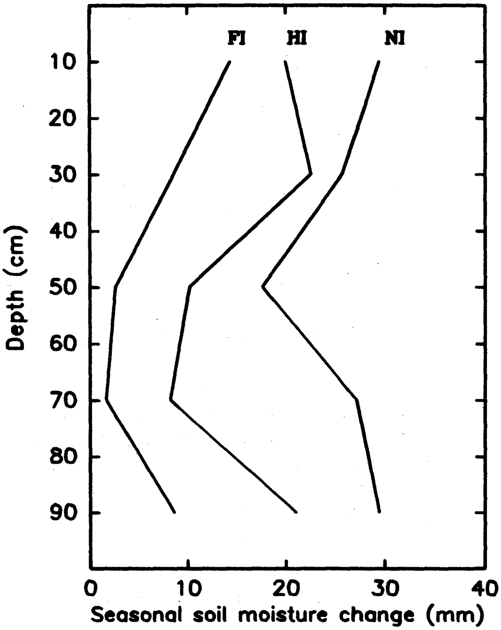

Figure 4: The influence of irrigation treatment on net seasonal soil changes under potatoes.

TABLE 4: Source of water used by the crop during the season.

Crop	Total water use (mm)	Rain + irrigation (%)	Change in soil water
Barley	310	46	56
Sugar beet	506	75	25
Potatoes (NI)	201	36	64
Potatoes (HI)	322	74	26
Potatoes (FI)	455	92	8
Avalon	516	77	23
Rongotea	486	82	18
Whero	394	79	21
Impulse	383	81	19

About 80% of the water use of the peas was from rain and irrigation (Table 4) and again the largest changes in soil moisture were near the surface with only small changes in the 50 cm layer and below. The moisture changes in the deep layers under the wheat and peas are as likely to have been associated with drainage as with extraction.

Table 3 gives net seasonal soil moisture changes for each layer. The magnitude of recharge by rainfall and irrigation can be seen in Figure 5 for irrigated potatoes and in Figure 6 for irrigated Avalon wheat. The upper two layers under the potatoes showed considerable fluctuation in moisture content due to root extraction and recharge.

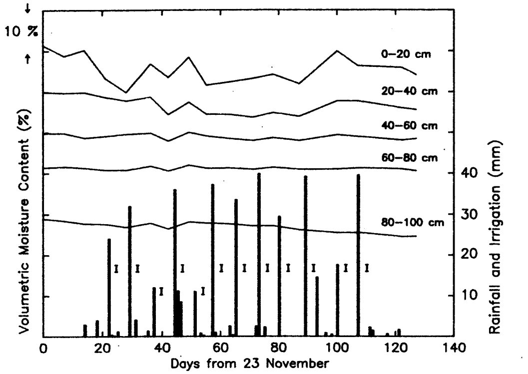

Figure 5: Changes in soil moisture content for five layers under an irrigated potato crop (FI) in 1981-82. Rainfall and irrigation (marked I) events are shown in the histogram. The moisture content curves are displaced vertically for clarity.

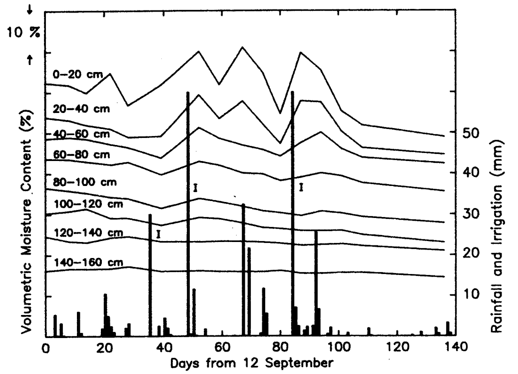

Figure 6: Changes in soil moisture content for eight layers under Avalon wheat in 1984-85. Rainfall and irrigation (marked I) events are shown in the histogram. The moisture content curves are displaced vertically for clarity.

There was little change in moisture content in the deeper layers. Irrigation therefore tended to confine soil moisture extraction to the upper profile. Under the wheat there was some variation in moisture content as deep as the 110 cm layer caused by percolation through the profile from the infrequent large irrigations. However, the greatest variation with extraction and recharge was in the upper 3 layers.

In all of the fully irrigated crops, soil moisture changes in the deeper layers were small. In these circumstances unequivocal conclusions about extraction from and percolation into these layers is difficult. However, for either of these processes to be substantial in these layers, they must very nearly balance. Although this may happen occasionally, it is unlikely to be frequent. Hence long periods (Figures 5 and 6) with little change in moisture content in deep layers may be taken as evidence of low extraction rates.

These results show clearly that crops will extract substantial amounts of water from depths of at least a metre when they need to. Where irrigation is applied, the crops will extract water from nearer the surface where it is most easily available.

The soil water extraction pattern from barley is mostly near the top of the profile similar to that reported for pasture (Hayman and Stoker, 1982). In contrast, water extraction patterns for sugar beet and unirrigated potatoes more closely resemble that of a deep rooted crop such as lucerne with fairly even extraction all the way down the profile (Hayman and Stocker, 1982). The results for sugar beet also suggest a substantial extraction of water from deeper than a metre. These results are related to root distribution and water availability. The fact that the barley was grown in a wetter season than the other crops may explain the greater water extraction in the upper profile.

When water budgets are used to schedule irrigation, water should be applied when the soil moisture deficit reaches some fixed fraction of the available water holding capacity of the soil (Jamieson *et al.*, 1984b). Calculations of available water holding capacities must take account of a sufficient depth of soil to account for the rooting depth of the crop, even when this contains a large proportion of stones (Hayman and Stocker, 1982). Because water is extracted from where it is most easily available, frequent small irrigations, which confine extraction to surface layers where nutrients are more concentrated, are likely to be more effective than infrequent large irrigations.

CONCLUSIONS

All of the crops studied were capable of extracting water from a depth of at least a metre, and the evidence suggested that extraction depth for sugar beet and potatoes was considerably greater.

Irrigation tended to confine extraction to the upper profile.

Net seasonal soil moisture changes under deep rooted, unirrigated or infrequently irrigated crops (sugar beet and potatoes) tended to be similar throughout the profile.

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