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The application of capacitance probes to study water infiltration under two irrigated potato crops in East Anglia.

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Executive Summary

The objective of this study was to examine how new soil water sensors could be applied to irrigated agriculture to improve understanding of water infiltration. The pilot study funded by the Institute of Hydrology and the Chadacre Agricultural Trust is a timely response to the recent droughts which have occurred in the South East of England. The study is aimed at demonstrating new technology and providing a stimulus for further, more intensive research into agricultural water management.

New instruments such as time domain reflectometry (TDR), capacitance probes and Theta Probes have been developed which give accurate estimates of soil water content. These are electrical sensors which are safe and can be automated. From a research point of view these instruments can be used to increase our understanding of soil water processes in order to improve irrigation management practices. From a growers point of view infield measurements of soil water content can be used by consultants to improve irrigation scheduling, optimising water management and the production of a high quality crop.

1. Introduction.

In the UK potatoes are the most important irrigated crop in terms of both area and volume of water applied. "If irrigation of crops ceased in the UK it is estimated that the value of crops lost would be £433 million. Agricultural water use nationally is 0.7-1.5% of the total water use, but is geographically skewed with up to half of the domestic supply equivalent being used for spray irrigation in E. Anglia in a dry year." (Stansfield, 1994). Potatoes and vegetables are the main crops irrigated. By 1996, potatoes covered 51% of the area under irrigation, compared with 32 % in 1990, and used ~50% by volume of the applied irrigation water (Stansfield, 1996). During 1995 and 1996 the UK suffered two very dry years causing pressure on growers to improve water use efficiency. Efficient use of water can be achieved only by gaining a firm conceptual understanding of soil water movement and distribution under a crop at a scale relevant to the plant. This knowledge can then be used to determine the best way to apply water. Good water management is required not only for growing a high quality crop but also as an aid to disease control. At present, the Ministry of Agriculture in the UK recommends that a deficit of no greater than 15 mm is allowed to develop during tuber initiation so that the surface of the potato is kept moist to prevent infection by scab. Soil water potential should go no lower than -20 kPa (Bailey, 1990).

Until recently in the UK water has generally been plentiful and so there has been little interest in the most efficient methods of water management in agriculture. The droughts that have occurred in the last ten years and increased demand on water resources are applying greater pressures in agriculture. Interest in applying new technology to aid water management, conserve water and use it efficiently has grown as accessibility to technology has increased and the cost reduced.

The UK potato market is highly competitive and growers are keen to gain answers to two main questions. The first regards potato quality: 'How much water do I need to apply to prevent scab?' The second is: 'Can I make more efficient use of my water and so reduce the number and/or frequency of irrigations?' In order to tackle field research into these questions it is necessary to collect high quality data at frequent enough time intervals so as to build up a picture of what happens within the soil surrounding the potato crop during and between irrigations.

Dielectric sensors such as those described in this report are particularly suited to this task. They provide a significant improvement in our ability to measure water content near to the soil surface on an almost continual time basis. Capacitance probes and TDR can be used effectively to measure soil water content in the 0 - 0.3 m zone and below (Payne and Bruck, 1996; Woodhead, 1996; Mead *et al.* 1996), producing data sets containing frequent measurements relevant to the scale required. Until recently, instruments for monitoring soil water content, e.g. the neutron probe, have required slow and labour intensive manual reading and cannot be automated. Manometer tensiometers which measure soil water potential (Suction) also require manual reading. The neutron probe is poor at estimating water content near to the soil surface which is the zone of most relevance to the crop.

The time domain reflectometry (TDR) technique was applied by Singh *et al.* (1993) to provide soil water content measurement for validation of an irrigation scheduling model for potatoes. The measurements were taken weekly which under utilised the strengths of the TDR which lie in its ability to measure hourly or even more regularly. In this study of irrigated potatoes in E. Anglia an Automatic Soil Water Station (ASWS) was used to provide hourly estimates of water content and measurements of soil water potential and soil temperature at a series of depths within the soil. Rainfall and irrigation inputs were measured using a tipping bucket rain gauge linked to the soil station. The field season, with two crops, provided a good test of the instruments' ability to produce good quality data recorded at frequent time intervals.

2. Field site and methods.

2.1 Site and soil description.

The experimental fieldwork was carried out at Upton Suffolk Farms, Park Farm, Herringswell, Suffolk, UK. The soil is Red Lodge series within the Soil Survey of England and Wales classification (Avery, 1980). It is a sand and has an Ap horizon that is about 0.5 m in depth overlying a coarser sand. Both horizons contain flints and are de-stoned twice a year. The field site is level and the main soil properties are shown in Table 2.1 below.

Soil Horizon	Sand %	Silt %	Clay %	Total organic carbon %	pH	EC 1:5 Extract S m^{-1}
Ap	93.5	4.2	0.3	2.0	6.5	0.0295

Table 2.1. *Particle size and soil data from the field site at Park Farm.*

Water repellency

The intensive cultivation and practice of reworking crop foliage back into the soil has led to the development of a soil that is water repellent, and particularly so when the surface has been allowed to dry. The water repellency of the soil was measured by the water drop penetration time (WDPT) test (Krammes & DeBano, 1965). A soil sample which was air dry was packed into a 1.5 litre cylinder, 0.1 m in diameter. Ten drops of water were applied, using a dropper, to the surface of the air dried soil sample. The times taken for the water droplets to penetrate into the soil were measured. This procedure was carried out with the soil packed to five bulk densities (1.35 - 1.65 g cm^{-3}), representative of the soil in the field. The WDPT test groups soils into five classes according to the time taken for water penetration (Table 2.2.). A soil is considered to be wettable if the penetration time is under five seconds and increasingly water repellent for times longer than this.

WDPT (s)	Classification
<5	1 Wettable
5-60	2 Slightly water repellent
60-600	3 Strongly water repellent
600-3600	4 Severely water repellent
>3600	5 Extremely water repellent

Table 2.2. Soil classification according to the water drop penetration time test, from Krammes & DeBano (1965).

Crop and cultivation information

Two early potato crops were the focus of the study the first grown in ridges and the second in beds. The first crop was the Maris Bard variety. This crop was planted on the 10th of March (day 69) and harvested in the final week of June 1997 (day 170). The potatoes were planted in ridges which were 0.20 m high i.e. from the crest of the ridge to the base of the furrow; the ridge top, centre spacing was 0.75 m. The potatoes were planted at a depth of 0.14 m and a spacing of 0.15 m along each ridge. The canopy began to emerge around the 10th of April (Day 100). The second crop, which was the Carlingford variety, was planted on the 9th of July (day 190) and harvested in the final week of September 1997 (day 273). The potatoes were planted in beds 1.25 m in width, with a 0.6 m wide and 0.2 m deep furrow either side. Three tubers were planted across the bed at a depth of 0.1 m and spacing of 0.15 m (the spacing along the bed was also 0.15 m). Emergence was noted around the 29th of July (Day 210).

Irrigation.

Irrigation water was applied in April in order to wet the surface soil. From mid May it was applied on a five day rota where possible to prevent a deficit greater than 15 mm from building up and so act as a scab control. The water was applied via a hosereel boom irrigator (Figure 2.1) which applies water to a width of 72 m of soil. The irrigator takes approximately one and a half minutes to apply ~ 19 mm of water to a given point on the soil surface. A single drag of the boom irrigator covering a distance of 330 m took approximately 8 hours.

***Figure 2.1**. The boom irrigator at the end of its pull over the experimental site.*

2.2. Automatic Soil Water Station (ASWS)

The installation layout of the soil water station is illustrated in Figure 2.2. It comprised: a tipping bucket rain gauge, calibrated to measure rainfall in 0.5 mm increments; three pressure transducer tensiometers to measure soil water potential, three capacitance probes to estimate water content and three thermistors to measure temperature. These were all connected to a Campbell CR 10 data logger which was set to record measurements hourly. The logger was powered by a 12v battery, trickle charged from a solar panel the advantage of which is that cables streching across the field were not required. The soil sensors were installed at 0.15, 0.25 and 0.5 m depth below the top of the ridge/bed. The ASWS data was supported by manual field observations which were required to link above ground activities with below ground measurements. This included digging into the ridges at different times to observe the wetting patterns in the soil.

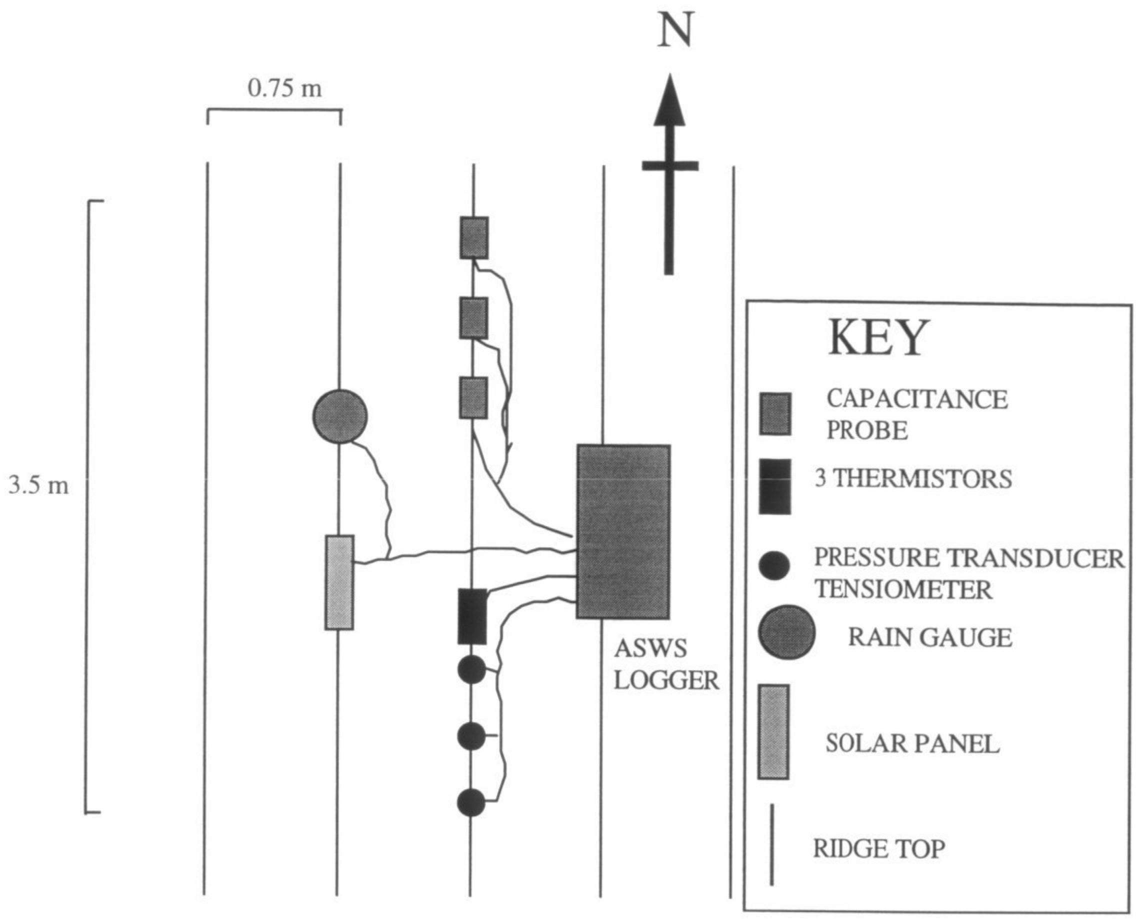

Figure 2.2. *The layout of the ASWS for the first crop. The layout for the second crop was the same with the instruments situated between the middle and outer plant rows within the bed.*

The capacitance probes at 0.15 and 0.25 m were installed by digging back the soil and inserting the electrodes horizontally into an undisturbed soil face between two sets of potato plants; the hole was then carefully back filled with soil. The probe installed at 0.5 m depth was inserted via a plastic access tube inserted into the ridge at 45°. The tensiometers were installed vertically about 0.5m apart. The thermistors were installed down an augered hole which was back filled.

Capacitance probes

Advances in electronics and instrumentation has allowed the development of new sensor techniques. Our understanding of the dielectric properties of soils has lead to a variety of techniques which measure soil permittivity (Topp *et al.* 1980; Dean, 1994 and Gaskin & Miller 1996; Platineau and Starr, 1997); from which soil volumetric water content can be accurately estimated. Techniques such as TDR (Topp *et al.* 1980; Skaling, 1992) and capacitance probes (Dean 1994; Perdock *et al.* 1996; Robinson *et al.* 1998) are safe, rapid, loggable and can be used to within a few centimetres of the soil surface depending on instrument configuration. The capacitance probes used in this study are an experimental design from the Institute of Hydrology. The sensor comes in three versions; a hand held field instrument, a buriable sensor which is connected to a logger and a portable depth probe, which is inserted into a plastic access tube installed in the soil (Dean *et al.* 1987). Schematic diagrams of the hand held sensor and depth sensor are shown in Figure 2.3. The instruments have 0.1 m electrodes shortened to 0.05 m using a plastic spacer. The sensors were calibrated specifically for the soil by using cores of repacked soil. Linear regression was used to give a soil specific calibration between water content and sqrt apparent permittivity (K).

$$\theta = \frac{\sqrt{K} - 1.42}{12.34} \qquad (R^2 = 0.995) \qquad (2.1)$$

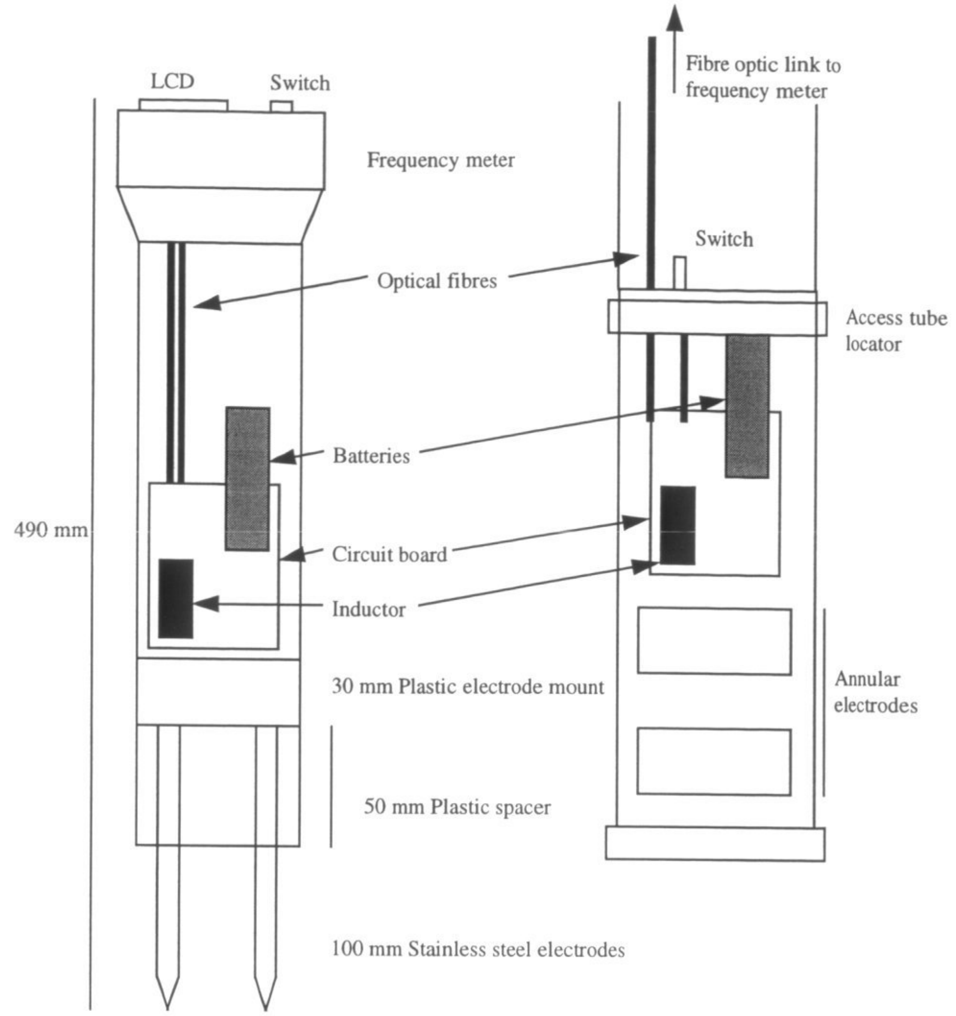

Figure 2.3. *The hand held surface capacitance insertion probe (SCIP) left and the depth probe right.*

Pressure transducer tensiometers.

The pressure transducer tensiometers are manufactured at the Institute of Hydrology (Wallingford, Oxon). They come in a range of lengths from 0.3 - 3.0 m according to the depth to which they are to be installed. The tensiometers were installed through access tubes, 50 mm in diameter. Each tensiometer is constructed with a high quality pressure transducer mounted 0.12 m above the middle of a 0.04 m long porous ceramic cup. Each can be filled with water and purged of air from the soil surface without the need to remove them. They are filled with de-aired water prior to instalment, and installed after wetting of the porous cup has been observed then allowed to equilibrate with the soil in *situ*. Figure 2.4 is a photograph of the field site; the metal tensiometer heads can be seen in the left row and the logger box in the right.

The tensiometer measures the soil water potential that the plant will experience. The data are plotted as the total hydraulic potential. This is the sum of the water potential measured by the tensiometer and the gravitational potential which depends on the tensiometers depth below the soil surface.

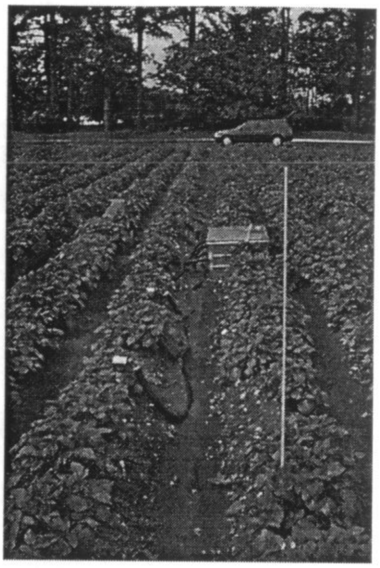

Figure 2.4. The first crop ASWS installation.

Thermistors

The thermistors were used to measure the soil temperature. These are cylindrical, 0.08 m in length and 0.005 m in diameter. The material inside the thermistor changes in electrical resistance as soil temperature changes occur; they measure accurately to 0.1 °C.

3. Results

3.1 Soil water repellency

The water drop penetration times for the Red Lodge soil fell into, or close to, class 2 which is the slightly water repellent class (Figure 3.1).

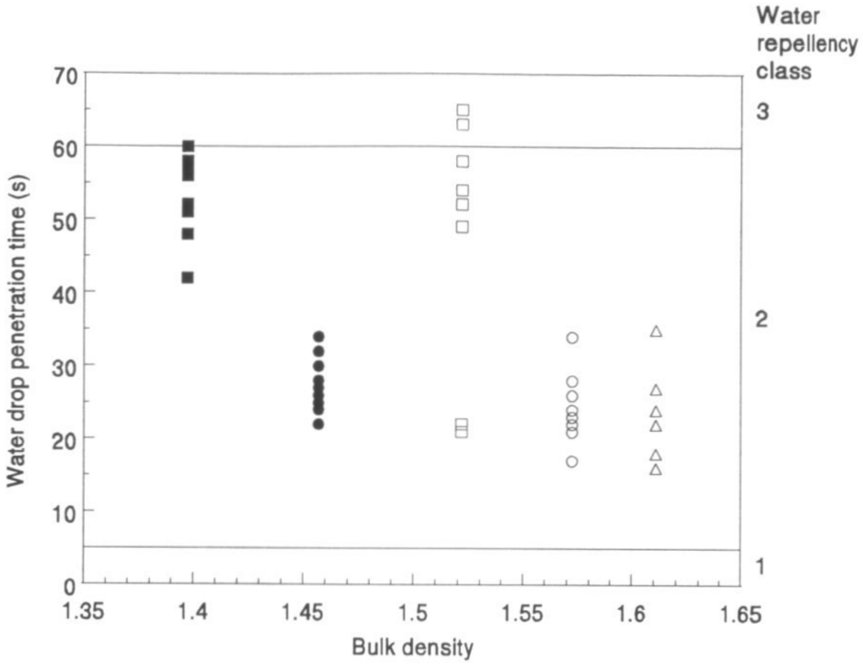

Figure 3.1. *The water drop penetration times for the Red Lodge soil at a range of bulk densities.*

The scatter in the data is likely to be a function of the scale at which the measurements were taken and spatial variability of the soil surface. The measured bulk density was an average of the 1.5 litres of soil used in this test but this may have varied locally at the surface of the cylinder due to packing. The overall consistency of the results, all falling in the same water repellency class, suggests the test is representative of the soil in general and that water repellency class does not alter as a function of bulk density.

3.2. ASWS results; First potato crop

Rainfall and irrigation

The ASWS was installed for 91 days during which 123.0 mm of rain fell on the field and 124.5 mm of irrigation was applied (Table 3.1) giving a total of 247.5 mm of water. The aim was to apply 19 mm of water in each irrigation; in practice irrigations averaged towards 21 mm, applied on average in a minute and a half. The distribution of the rainfall / irrigation inputs over time can be seen in Figure 3.2.

Date	**Julian day**	**Rainfall**	**Irrigation**
23 March 1997	82	0.5	
24 March 1997	83	1.0	
25 March 1997	84	1.0	
27 March 1997	86	2.0	
14 April 1997	104		20.5
19 April 1997	109		24.5
25 April 1997	115	9.0	
26 April 1997	116	2.0	
27 April 1997	117	0.5	
28 April 1997	118	0.5	
04 May 1997	124	1.0	
05 May 1997	125	8.0	
06 May 1997	126	4.0	
08 May 1997	128	5.5	
09 May 1997	129	5.0	
11 May 1997	131	4.5	
12 May 1997	132	0.5	
15 May 1997	135	1.0	
16 May 1997	136	3.5	
18 May 1997	138	0.5	18.0
20 May 1997	140	3.0	
24 May 1997	144		20.5
28 May 1997	148		23.0
05 June 1997	156	8.5	18.0
06 June 1997	157	7.0	
07 June 1997	158	13.0	
08 June 1997	159	6.0	
11 June 1997	162	31.0	
12 June 1997	163	2.5	
14 June 1997	165	0.5	
15 June 1997	166	1.5	
TOTALS		123.0	124.5

Table 3.1. *Rainfall and irrigation figures from Julian day 78 - 169.*

ASWS soil data.

At the start of the season the soil was cultivated and ridged for the potatoes. The surface of the soil dried and acted as a mulch so that very little soil water was lost to evaporation from the bare soil surface. The data for the first crop obtained with all the sensors installed in the field are presented in Figure 3.2. During the growth of the crop the soil water content remained between 0.15 and 0.05. The soil water potential measured by the tensiometers followed the soil water content as one would expect. The potentials remained above -80 kPa until two weeks before the crop was harvested. The soil temperatures were observed to rise from about 10 °C at the planting of the crop to about 16 °C by the time the crop was harvested. Diurnal fluctuations in temperature were observed in both the soil water potential and the soil water content.

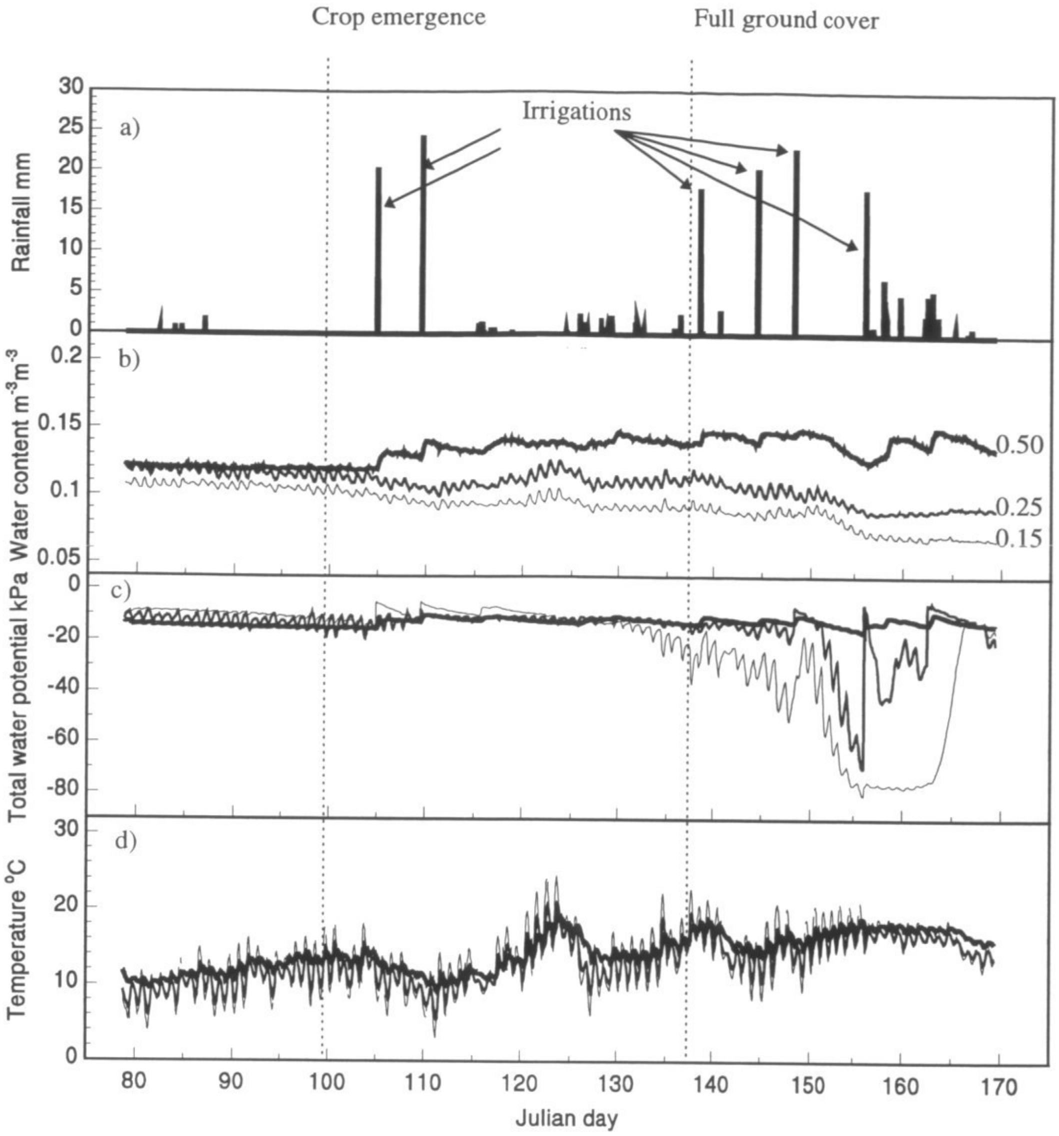

Figure 3.2. *a) Rainfall/irrigation; b) Soil water content; c) Total hydraulic potential; d) soil temperature, all soil measurements at 0.15, 0.25 & 0.5 m below the top of the ridge in the early potato crop.*

Soil water content and potential

Figure 3.2b shows the soil water contents measured by the sensors installed at depths of 0.15, 0.25 and 0.5 m. During the first ten days after the installation of the ASWS, soil water content changed negligibly. The soil water content at the time was therefore considered to be field capacity. The volumetric water content was 0.12 at the more compact, lower depths in the soil, and about 0.11 in the lighter ridge soil. Field capacity is the soil water content reached when drainage due to gravity stops (Bailey, 1990). For this soil, field capacity at these water contents was supported by the soil water potentials of -10 kPa measured by the tensiometers (Figure 3.2c).

As the crop began to emerge (day 100) so the water content sensors at 0.15 and 0.25 m responded, showing drying. The first irrigation was applied on day 104 but the 0.15 and 0.25 m sensors showed little reaction to this irrigation. The first rise in water content was measured by the 0.5 m sensor. It was expected that any measured rise in water content would be sensed first at the shallowest sensor within the ridge 0.15 m and then at 0.25 m as the soil wetted. However, over the following ten days the 0.15 and 0.25 m sensors showed a decrease in measured soil water content (Figure 3.2b). This conflicted with the tensiometer data which showed the soil wetting slightly for the same period. During the second irrigation on day 109 it was found that as the irrigator passed over, water was sprayed onto the access tubes in which the tensiometers were installed. To eliminate the possibility of water collecting and running down the side of the access tube into the soil immediately around the tensiometer cup plastic skirts were fitted around the tensiometer tops to shed the water out onto the surrounding soil.

The soil water contents measured between days 105 and 115 seemed quite anomalous as 45 mm of irrigation was applied but there was no associated increase in water content at 0.15 or 0.25 m; indeed at these depths the water content decreased by about 0.01. As the season progressed the same pattern was observed with the water content declining in the ridge and wetting occurring at 0.5 m. A little recharge occurred within the ridge after the rain events on days 115, 126, 157 and 162 but the irrigations appear to have had little or no effect. This lack of soil moisture recharge within the ridge resulted in a distinct soil water deficit developing through the lifetime of the crop (Figure 3.4). This gradual build up of a deficit within the ridge was supported by the tensiometer data which showed gradual drying then a large decrease of potential from day 130 onwards.

Field observations

After each irrigation there was a noticeable difference between the colour of the soil making up the ridge and that which was in the furrow. The wetter soil in the furrow appeared much darker and the soil surface appeared to be a stripy brown.

Figure 3.3. *A section through the ridge, the light coloured region of soil highlighted by the black line is dry and clearly visible. The water content of this zone was measured using a capacitance probe and found to have a water content of 0.06 even after 25 mm of rain had just fallen.*

The photograph in Figure 3.3 shows a cross section through a ridge. It was taken after a rainstorm on day 162, the soil was dug back, observed and photographed. After 25.0 mm of rain the dry core of the ridge was clearly dry. The dry core within the ridge was observed every time a cross section was dug through one of the ridges and observed. This was carried out five times at different locations around the field during the growing period. It was observed that a 30 - 40 mm layer of soil wetted at the surface of the ridge, the water then flowed along this conductive pathway, into the furrow where it infiltrated. The dry ridge core developed early in the season and became dryer as the crop extracted more water. The water repellent nature of the soil encouraged this process, the drier the antecedent conditions of the soil the more it impeded water penetration. This is the reason why the water content sensors at 0.15 and 0.25 m showed a gradual drying throughout the growth of the first crop (Figure 3.2b).

Soil water storage

Soil water storage was calculated based on the water content measurements made by the capacitance probes. The water content measured by the capacitance probe at 0.15 0.25 and 0.5 m were assumed to represent soil layers of 0 - 0.2 m, 0.2 - 0.3 m and 0.4 - 0.5

m of soil respectively; 0.3 - 0.4 m was taken as the average of the water contents for 0.25 and 0.5 m. A soil water deficit was found to exist in the 0.5m of soil belo the ridge top.

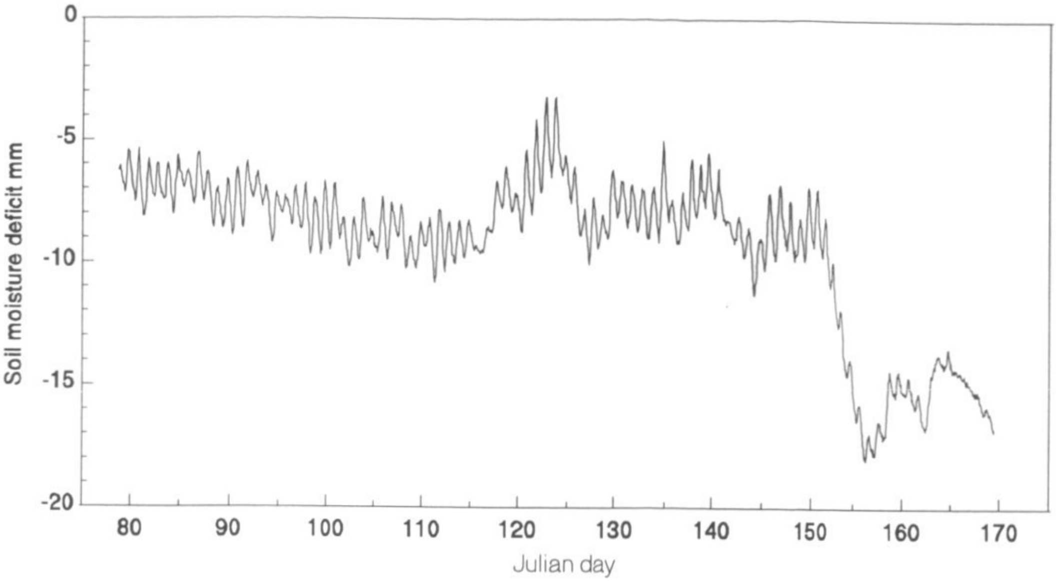

Figure 3.4. *The soil water deficit for the upper 0.5 m of soil beneath the ridge, calculated from the water contents measured by the capacitance probes located in the ridge.*

The graph of soil water deficit (Figure 3.4) exhibits diurnal fluctuations in soil water deficit. These are most probably due to temperature fluctuations, the trend in soil water deficit remains clear. A line, drawn through the mid points of the diurnal highs and lows is probably a better estimate of the changes in soil water deficit.

Soil temperature.

The soil temperature showed a large diurnal range at 0.15 and 0.25 m (Figure 3.2d). The range at 0.15 m was as large as 8 °C with 4 °C at 0.25 m. Two late frosts occurred on days 111 and 127, with the former being the most severe; both frosts set the crop back. From day 119 the daytime soil temperature at 0.15 m stayed above 15 °C.

In situ water release

An advantage of running water content sensors in parallel with tensiometers is that the wet end of the soil water release curve can be established *in situ*. The water release characteristics for the different depths are demonstrated in Figure 3.5. As there was no significant increase in soil water content during the wetting events due to the water running off because of the soils water repellency, the wettest part of the release curve is absent. The important points to note are that the soil in the ridges never fully wetted and that there will have been no drainage from beneth the crop.

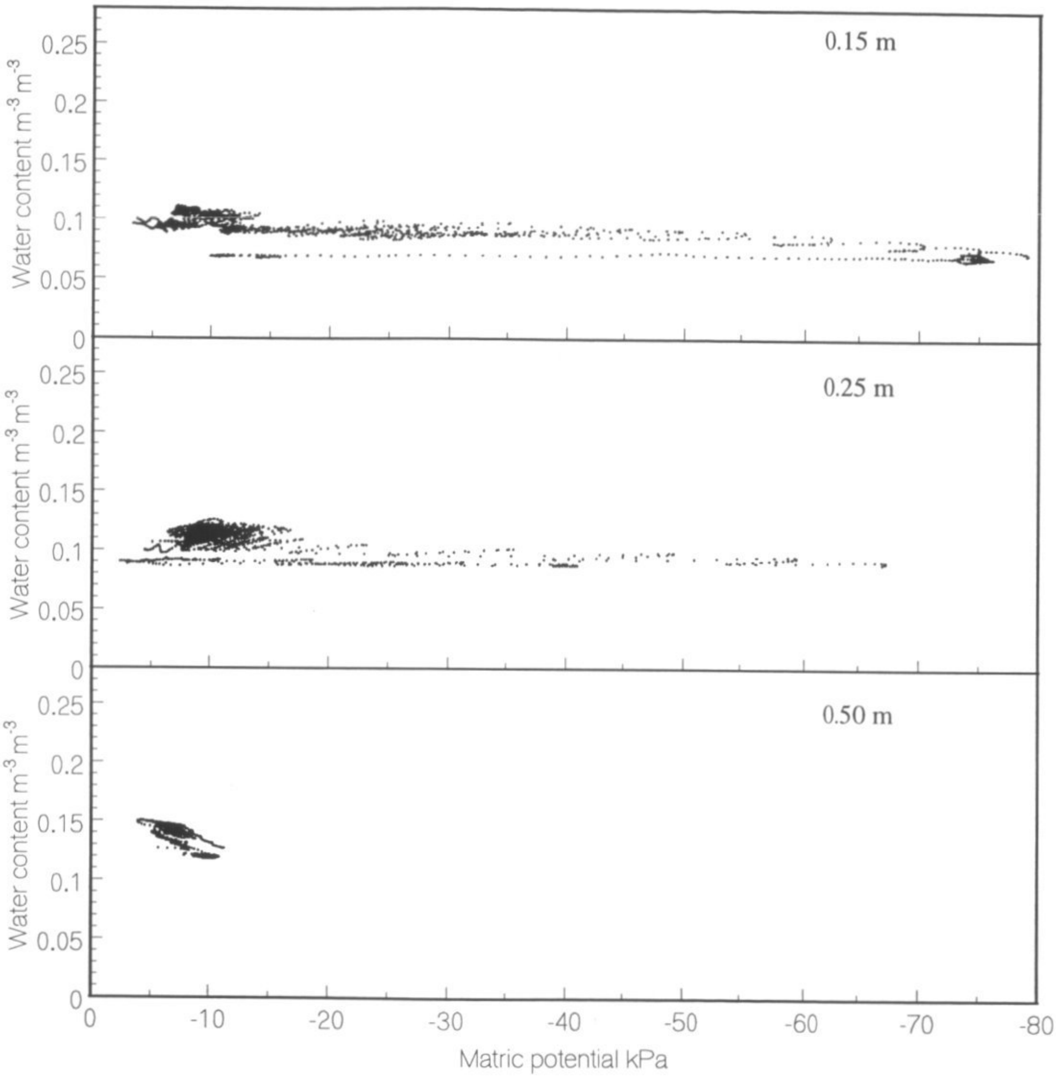

Figure 3.5. *In situ soil water release curves plotted from the capacitance probe and tensiometer data.*

3.3 ASWS results; second potato crop

Rainfall and irrigation

Date	Julian day	Rainfall (mm)	Irrigation (mm)
17 July 1997	198	8.0	
18 July 1997	199	4.0	
22 July 1997	203	8.5	19.0
24 July 1997	205	0.5	
26 July 1997	207	1.0	
28 July 1997	209		9.5
30 July 1997	211	2.5	
31 July 1997	212	1.5	
01 August 1997	213		16.0
08 August 1997	220	10.0	21.5
12 August 1997	224	9.5	
13 August 1997	225	19.0	20.5
20 August 1997	232		24.5
21 August 1997	233	0.5	
22 August 1997	234	1.5	
23 August 1997	235		19.0
25 August 1997	237	8.0	
27 August 1997	239	4.0	
28 August 1997	240	6.5	
28 August 1997	242	6.0	
03 September 1997	246	1.0	
05 September 1997	248	0.5	
06 September 1997	249	1.5	
11 September 1997	254	2.0	21.0
12 September 1997	255	2.0	
18 September 1997	261	1.0	
19 September 1997	262	2.5	
22 September 1997	265	22.0	
23 September 1997	266	0.5	
27 September 1997	270	22.5	
TOTALS		146.5	151.0

Table 3.2. Rainfall and irrigation figures from Julian day 195 - 272.

The soil was cultivated for a second time in late June / early July. This time the potatoes were planted in beds ~ 1.25 m across with three rows in each bed. The 66.0 mm of rain which fell in late June early July thoroughly wetted the soil bringing the water content back to field capacity. The ASWS was installed for the second time on the 14th of July (5 days after planting) for 77 days, during which 146.5 mm of rain fell on the field and 151.0 mm of irrigation was applied (Table 3.2) giving a total input of 297.5 mm of water. The average irrigation for the 8 applications was 19 mm, though this contained some variability.

ASWS data.

The data for the second crop is presented in Figure 3.6. The time between the crop emerging and full ground cover being achieved was shorter as expected. The sensors installed in the beds responded to the irrigations and rainfall. The soil wetting and draining at each event. The soil temperature was at its highest for the summer months of July and August and declined steadily in September.

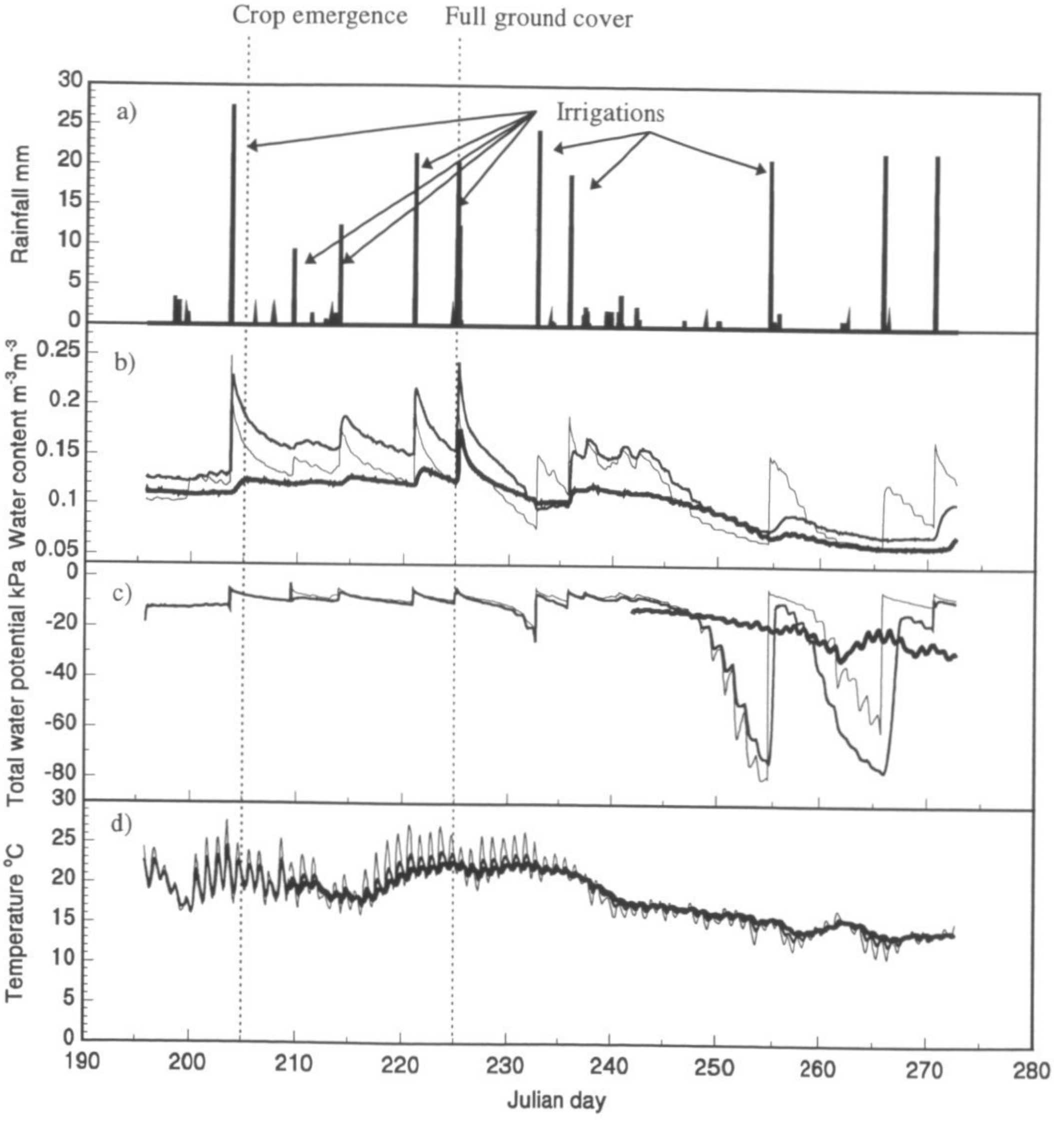

Figure 3.6. *a) Rainfall/irrigation; b) Soil water content; c) Total hydraulic potential; d) soil temperature, all soil measurements at 0.15, 0.25 & 0.5 m below the top of the bed in the second potato crop.*

Soil water content and potential

The sensors installed in the bed responded to the application of water at each rainfall and irrigation event (Figure 3.6b). This was the type of response which had been expected but not observed for the first crop. Each irrigation infiltrated into the bed and so the soil water deficit was recharged after each irrigation (Figure 3.7). A lag was observed between the wetting of the soil at the top of the ridge and the sensor responding at 0.5 m (day 204 - 205). By day 225 this lag had gone and the sensors all responded together as soon as the water was applied.

Emergence occurred around day 205. The irrigations proved to be very effective at rewetting the bed and maintaining the water content close to field capacity during the period of tuber initiation (day 210 - 240). In the week after full ground cover was achieved (day 225 - 232), the response of the capacitance probes clearly indicated that the crop was effectively drawing water from 0.15 and 0.25 m.

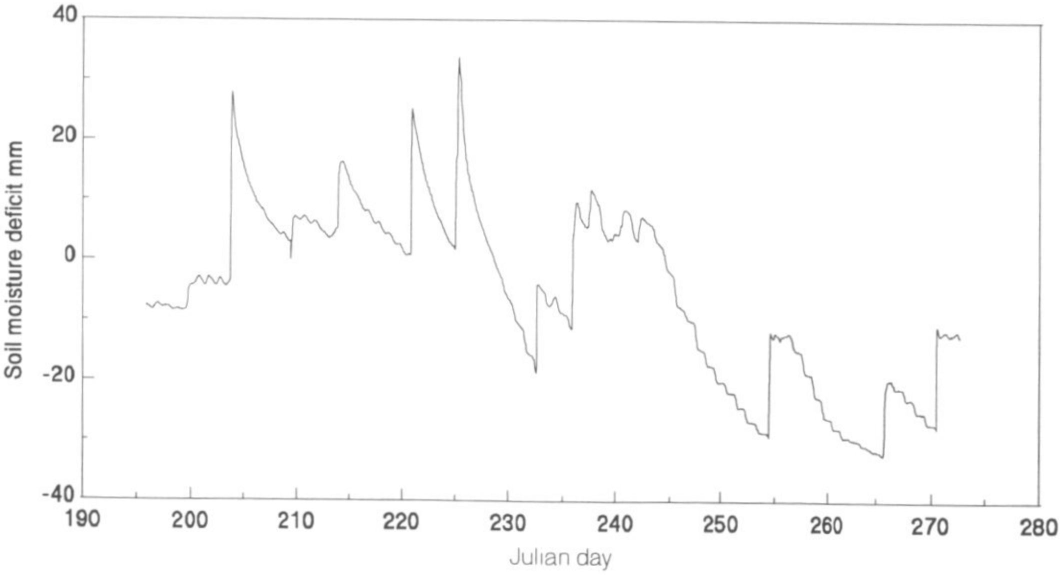

Figure 3.7. *The soil moisture deficit / surplus for the upper 0.5 m of soil, determined from the results from the capacitance probes located in the bed.*

By day 250 the same was occurring at 0.5 m. Once again the capacitance probe data is supported by the tensiometer data (Figure 3.6c). The tensiometer at 0.5 m failed to work initially and was replaced at the end of August.

Soil temperature.

The soil temperature at all depths hovered around 20 °C during July and August and showed daily maximums of ~25 °C at 0.15 m. The cable to the 0.5 m thermistor was found to be damaged and was replaced on day 210.

In situ water release

The infiltration of water into the beds allowed for the production of soil water release curves with the very wet end present. The data for 0.15 and 0.25 m was very complete, throughout the working range of the tensiometers (Figure 3.8).

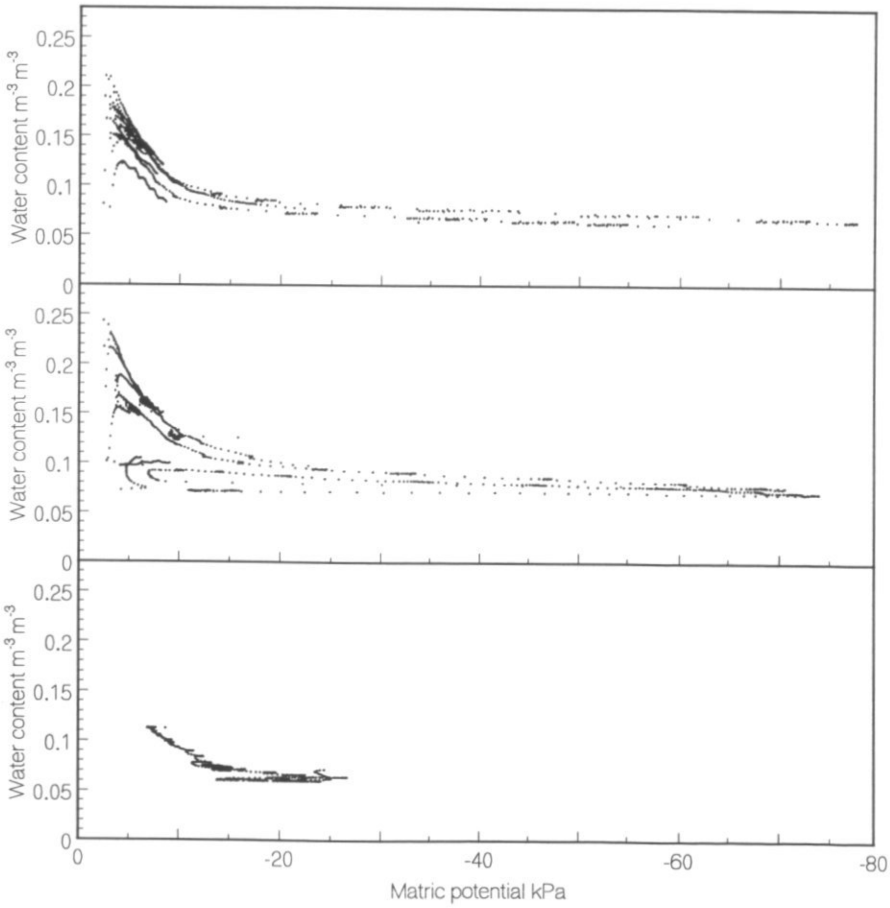

Figure 3.8. *In situ soil water release curves plotted from the capacitance probe and tensiometer data, the 0.5 m data is limited due to the breakdown of the tensiometer at the start of monitoring.*

Below a water content of 0.10 the matric potential declines rapidly. The associated effect will be a reduction in the hydraulic conductivity of the soil which inhibits the redistribution of water within the soil profile. The graph further demonstrates that the water available to the crop is very limited; effectively between 0.25 at saturation and 0.08. Below a water content of 0.08 the crop has to work progressively harder to draw water from the soil.

4. Discussion

Conceptual understanding of infiltration into ridge and bed cultivation.

The data from the ASWS allows the building of a conceptual understanding of the soil water processes occurring in the two cultivation systems. The data for the first crop planted in the ridges indicates an increase in the soil water deficit at 0.15 and 0.25 m during the growing time of the crop, despite irrigation and rainfall inputs. This interpretation is based on the reduction of soil water content measured by the capacitance sensors at 0.15 and 0.25 m (Figure 3.2b). Observation of the first two irrigations applied to the crop suggested that the water that was applied from the boom was shed off the ridges and into the furrows. This may have two causes; the first being the slope of the ridges which are composed of a water repellent soil. When the surface of the soil is dry, as it was for the first irrigations, water finds it difficult to penetrate into the soil. The tendency is for the water to run to the lowest point of the furrow, pond and infiltrate at this point; this was observed in the field during a number of irrigations. The second factor which will contribute to runoff from the ridges into the furrows, is the rate at which water is applied from the boom. 19 mm of water was applied to each square metre of soil in one and half minutes. A typical rainstorm will apply 5 - 10 mm per hour and a thunderstorm as much as 50 mm per hour. Therefore the application rate is nearly 150 times greater than a rainstorm and 15 times greater than a UK thunderstorm. This will generate runoff from the ridges even in soils with a high hydraulic conductivity. Therefore the water repellency of the soil, the slope of the ridges and the high water application rate all contribute to irrigation water running off the ridges and infiltrating in the furrow bottoms. This may be reduced by slowing the irrigation application rate and the rate of travel of the irrigator over the field. This will be most important early in the growing season. Once the soil is wet infiltration will improve.

The shedding of water into the furrows is likely to be exacerbated as the crop emerges and grows. The canopy of the crop may act rather like an umbrella, again causing water to be shed into the furrows. The canopy may have some positive effect, gathering water which may flow down the stem and infiltrate at the base of the stem directly on to the potatoes. However, this was not observed in the field. The weight of the water on the canopy bent the leaves down and so intercepted water was shed into the furrows. Based on the ASWS data (Figure 3.2) and the field observations (Figure 3.3) Figure 4.1 shows a conceptual diagram showing the major water flow pathways within the soil for a ridge cultivation system.

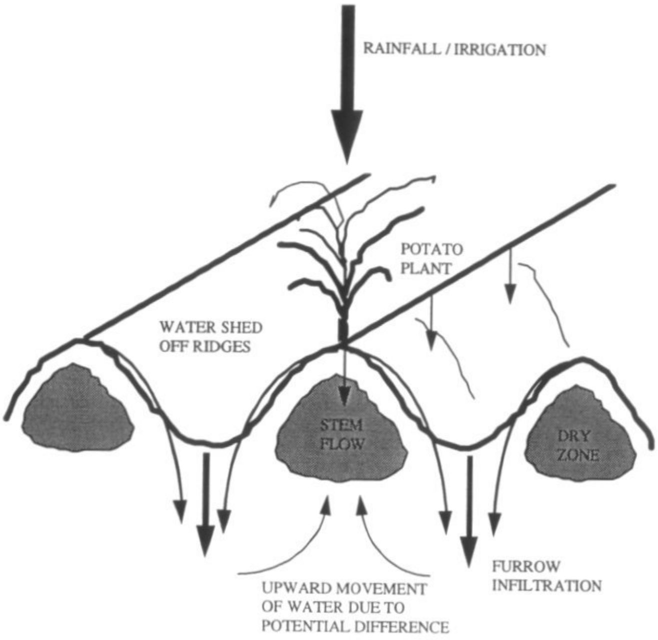

Figure 4.1. *Conceptual diagram of water infiltration pathways for a potato crop planted in ridges.*

The change to bed cultivation for the second crop resulted in a substantial improvement in terms of water penetration into the soil around the potatoes. The level surface of the bed allowed more water to be captured and held on the soil surface providing time for it to infiltrate. Some water was observed to run off the edges of the beds as it was applied from the irrigator but the instruments and observation of the bed in cross section, demonstrated good water penetration. This is shown in a conceptual diagram, Figure 4.2.

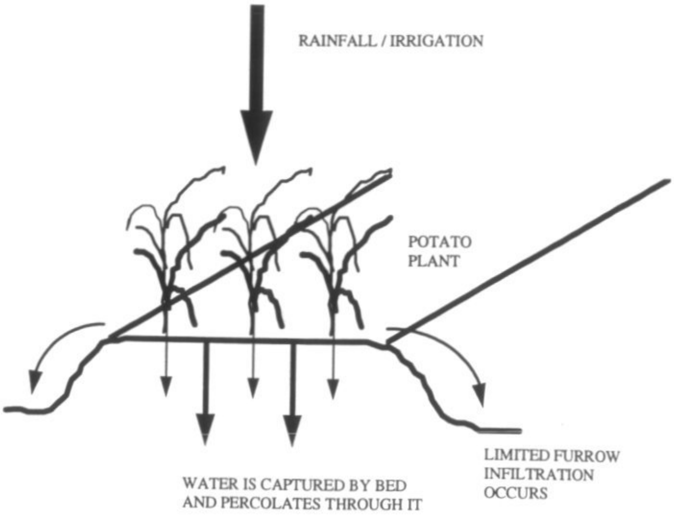

Figure 4.2. *Conceptual diagram of water infiltration into the bed cultivation system.*

In order to provide a complete comparison of ridge and bed cultivation, a side by side field trial would be required which unfortunately was beyond the scope of this piece of work.

Soil water management and disease control.

The results from this experiment have some major implications for the way water is applied to potato crops grown in water repellent sandy soils. Potatoes are conventionally cultivated in ridges and growers believe that the water they apply is penetrating into the ridges; being used by the potatoes and protecting them against scab. In the beds, this is likely to be the case but the evidence from this work suggests that the contrary is true for ridge cultivation in these light water repellent soils under this regime of surface irrigation.

Ridge cultivation for the first early crop is used primarily to exploit the spring sunshine, increasing the temperature in the ridges so as to induce early crop emergence. Whether there is an advantage in terms of soil temperature, early emergence and better yields over beds has not been established and would prove a valuable contribution to this work. What is important is that ridges which are dry conduct heat more readily, which is an advantage for warming the soil but a disadvantage if a frost strikes. Keeping the ridges wet will reduce the frost risk as the wet soil is less conductive to heat, but as this work has demonstrated, the irrigation was not wetting the soil.

5. Conclusions

The major conclusion is that under this type of irrigation and application rate on light, sandy, water repellent soils, enhanced water runoff occurs if ridge cultivation is used for growing potatoes.

The use of bed cultivation considerably improves water infiltration around the crop. If ridges are important then adjustment of the rate of application of irrigation water may improve infiltration into the ridges.

The instrumentation used in the study proved to be very effective for characterising flow pathways of irrigation water infiltrating into the soil. Advances in this technology are making it more accessible to growers through consultants offering instrumentation, monitoring and advice.

This sort of instrumentation requires a skilled user for both the installation and interpretation of the data. This may keep it in the domain of the consultant rather than individual grower. Accurate interpretation may have profound impacts on both crop yield and quality.

Good observation combined with accurate measurement and good interpretation has proved successful in aiding understanding of the soil water processes beneth the potato crop. Growers should be encouraged to continue the practice of field walking and link any observations in the field with any information from soil water sensors.

More intensive study would enable more serious quantification of the processes and enable the construction of a water balance which would partition how much water infiltrates into the soil in the ridge/bed; how much infiltrates in the furrows; how much stem flow occurs and the losses to evaporation. Further work must incorporate the relative difference in temperature between ridge and bed cultivation in the early part of the year. This information could then be turned into estimates of efficiency improvements and economic gains made by the respective cultivation practices.

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