Effects of a subsurface interception drainage system on soil moisture regime in a saline-seep area

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Beke, G.J., Graham, D.P. and Entz, T. 1993. **Effects of a subsurface interception drainage system on soil moisture regime in a saline-seep area.** Can. Agric. Eng. **35**:175-181. The temporal and spatial relations of soil water with interception drainage of a side-hill saline seep area, cropped partly to alfalfa, in southern Alberta was characterized from 1986 to 1988. The three interceptor drains were at a depth of 1.55, 1.67, and 1.78 m, respectively, approximately midway down the drainfield. Their effect on phreatic level and soil-water content was more pronounced upslope than downslope from the drainlines. Soil-water content in the 0 - 1.50 m depth decreased over time with increase in depth to watertable. Spatially, the soil water indicated a critical depth of capillary rise of water from the watertable of between 1.60 and 2.00 m, with the latter depth substantiated by simulation analysis. These improvements in soil-water regime and phreatic level will aid in assessing the adequacy of interception drainage for salinity control and crop production.

Les relations temporelles et spatiales entre l'eau du sol et le drainage d'interception dans une zone d'infiltration saline sure le côté d'une colline partiellement couverte de luzerne dans le sud de l'Alberta, ont été étudiées entre 1986 et 1988.Les trois drains d'interception étaient respectivement enfouis à une profondeur de 1,55, 1,67 et 1,78 m, approximativement à mi-chemin dans la zone de drainage. Leur effet sur la hauteur de la nappe phréatique sur le contenu hydrique du sol était plus prononcé au haut de la pente des lignes de drainage qu'aux points les plus bas. Le contenu hydrique du sol entre 0 et 1,50 m a diminué dans le temps, avec une diminution de la hauteur de la nappe phréatique. Concernant l'aspect spatial, l'eau contenue dan le sol a indiqué une profondeur critique de montée de l'eau par capillarité à partir de la nappe phréatique variant entre 1,60 et 2,00 m. la dernière profondeur ayant été établie par simulation. Ces améliorations dans les régimes hydriques du sol et la hauteur de la nappe phréatique aideront à évaluer la suffisance du drainage d'interception pour le contrôle de la salinité et de la production de plantes.

INTRODUCTION

In non-irrigated agricultural land of semi-arid areas, drainage systems are installed both to remove excess water and to control or reduce soil salinity. Soil reclamation under saline conditions requires that more salt must move downward than moves upward in the soil. Therefore, the salt balance of these soils depends largely on the water balance, although the salt balance should determine the adequacy of drainage (Rhoades 1990).

By the end of 1985, about 260 mostly small (8 ha) subsurface drainage systems had been installed in dryland areas of southern Alberta. The rate of installation increased annually from 1974 to 1982 and declined subsequently (Harker and Mikalson 1986). Due to the economic downturn and drought of the 1980's, the decline has likely continued to the present. Despite this decline, the performance of drainage systems needs to be determined, as dryland salinity is a continuing problem in the semi-arid prairies.

An interception drainage system was installed in a sidehill saline-seep area near Lethbridge, AB, during the winter of 1977-78. Direct determination of drain-system performance by drain discharge was not conclusive in the early stages of the project owing partly to failure of monitoring equipment and the drought of the early to mid 1980's. The effectiveness of subsurface drainage can, however, be evaluated by indirect means, such as change in soil physical properties (Hundal et al. 1976), soil moisture regime characteristics (Larney et al. 1988), and crop yields (Bolton et al. 1980; Fausey 1983). All known appraisals dealt with drainage systems installed in long-term poorly drained soils on nearly level terrain. The objectives of this study were to determine the temporal and spatial characteristics of the soil-water regime associated with an interception drainage system in a recently developed sidehill saline seep.

MATERIALS AND METHODS

The study site was located 0.5 km south of Nobleford, AB. It was situated on a 7% south-facing slope of a 425 ha closed watershed at an average elevation of 969 m above mean sea level. Dark Brown Chernozemic soils predominate in the basin (Alberta Institute of Pedology 1977). The soil at the site was a clay loam to sandy clay loam texture and had developed in glacio-lacustrine deposits. The seepage area under study was well established by 1960 and was sustained by groundwater coming from a northeasterly direction (Sommerfeldt and MacKay 1982).

Experimental layout

In the winter of 1977-78, three 100 mm diameter perforated corrugated plastic drains were installed perpendicular to the land slope at variable spacing and length (Fig. 1). A similar drain was installed around the perimeter of a backfilled reservoir within the seep area and joined with the middle lateral or interceptor drain. In 1984, drain depth about midway in the drainfield was 1.55, 1.67, and 1.78 m for the lower, middle, and upper interceptors, respectively. Drains discharged into

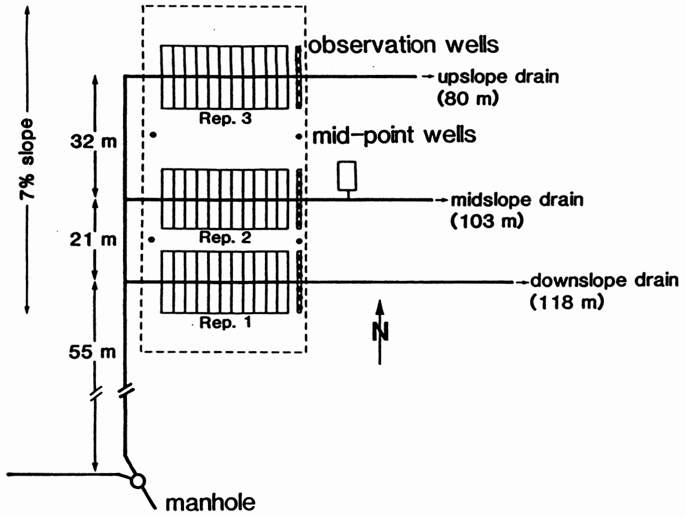

Fig. 1. Layout of subsurface drainage system and plot design.

a 150 mm diameter perforated corrugated plastic collector drain, which discharged into a constructed reservoir.

The western half of the drained area was fenced off in the fall of 1982. The following spring, groundwater observation wells were installed perpendicular to the interceptor drains and eleven 16 m x 3 m plots were laid out across each interceptor drain with plot length centered at the drainline. The plots in each replicate (Rep.) were then seeded to forage and oilseed crops according to a randomized complete block design. The crops selected were six varieties of alfalfa, tall wheatgrass, Altai wildrye, slender wheatgrass, sainfoin, and safflower. Crop establishment succeeded in 1985, except for sainfoin, which was replaced by flax starting in 1986. Soil physical measurements in 1983-85 were limited to characterization of soil morphological, physical, and chemical properties. Measurements of soil moisture were initiated in 1986, following installation of galvanized steel neutron probe access tubes in selected treatments. Of these treatments, the Roamer alfalfa plots selected for this study had the best perpendicular-to-slope alignments in the plot design. The access tubes were located 0.5 m and 7.5 m upslope and 7.5 m downslope from each interceptor drain based on observed differences in crop growth.

Monitoring

Air and soil temperature, precipitation, pan evaporation, and wind speed were monitored at a weather station established near the study area in 1975. Water levels in the observation wells were measured monthly with a graduated pliable plastic tube. Water levels in the wells midway between the interceptor drains were measured weekly. Volumetric soil-water contents were monitored biweekly during the growing season at the prescribed depths of 0.23, 0.46, 0.76, and 1.07 m, using a neutron moisture meter.

Analytical methods

Soil samples were taken to a depth of 1.5 m in the fall of 1988 to determine gravimetrically the spatial distribution of soil water. The Beaver and Trek alfalfa, flax, and tall wheatgrass treatments inside the enclosure and a transect in the uncultivated drainfield area were sampled at 1, 3, 5, and 7 m upslope and downslope from each interceptor drain. All other plots in the enclosure were sampled at 7 m downslope and 1 and 7 m upslope from the drainline. Samples were taken with a Giddings coring machine mounted on a 3/4-ton truck, using a 75 mm ID sampling tube. Four consecutive 0.15 m samples were taken over the 0 to 0.60 m depth and three 0.30 m samples over the 0.60 to 1.50 m depth. The core samples were placed in plastic lined bags to prevent air drying.

A subsample was taken from each sample for determination of bulk density according to method 2.213 outlined by McKeague (1978). A subsample of the remainder was weighed, oven-dried at 105°C, and reweighed for gravimetric determination of field moisture content. Average values of bulk density (Table I) were used to calculate the volumetric moisture content at time of sampling. Field data were used to calculate the steady state capillary rise from a groundwater level at 2.00 m beneath the soil surface, according to the computer program CAPSEV (Wesseling et al. 1984). Average clay, sand, and organic matter content (%) of the soil layers recognized for the simulation were: light clay loam 27.6, 35.2, 1.47; clay loam 30.1, 23.8, 0.69; loam 22.8, 28.5, 0.57 respectively.

Summary statistics were calculated for the soil-water content at each sampling location. A t-test was used to evaluate differences in soil-water content between neutron probes 1 m from the drainline and those 7 m from the drainline. The GPLOT procedure (SAS 1989) was used to plot monthly watertable hydrographs, which were compiled into a three year overview using AutoCAD (Autodesk 1990). SAS (1989) was also used to plot the soil-water contour and capillary-rise.

RESULTS AND DISCUSSION

Watertable level

The years of 1986 to 1988 were drier than normal (Table II) with few pronounced rises in the watertable but nearly continuous drainflow in the collector drain as two of the three

Table I: Average bulk density for each soil depth and replicate

Soil depth (m)	Bulk density ($Mg{\bullet}m^{-3}$)		
	Rep. 1	Rep. 2	Rep. 3
0.00-0.15	1.35	1.33	1.46
0.15-0.30	1.55	1.43	1.58
0.30-0.45	1.57	1.56	1.76
0.45-0.60	1.63	1.59	1.61
0.60-0.90	1.53	1.63	1.58
0.90-1.20	1.57	1.62	1.46
1.20-1.50	1.41	1.60	1.49

Table II: Mean monthly precipitation (mm) during the study period and over the long-term at the Nobleford site

Month	1986	1987	1988	59-yr Mean
January	3.0	6.0	6.2	15.1
February	18.7	2.8	6.4	16.5
March	10.3	39.5	22.5	21.9
April	13.0	8.5	0.0	24.5
May	48.8	9.0	16.5	47.6
June	10.9	48.1	50.6	68.9
July	32.0	79.5	13.0	35.9
August	6.1	47.0	49.9	41.2
September	74.4	21.5	13.8	36.0
October	44.9	15.5	14.4	17.2
November	1.4	2.2	1.8	14.5
December	2.6	10.8	12.9	16.0
Annual	266.1	290.4	208.0	355.3

interceptor drains were below or at groundwater level (Fig. 2). A watertable response to monthly precipitation was only evident following the 74 mm rain in September 1986, which raised the average October watertable by 250 mm. The abrupt mean 123 mm rise of the watertable in April 1987 was attributable mainly to the melting of snow and the thawing of soil. Sommerfeldt and Oosterveld (1977) also encountered high watertables at this time of the year, in irrigated land of the region. Early summer precipitation, even when greater than normal, usually did not cause a rise in the mean watertable, probably owing to the water demand of the growing vegetation. For instance, the August 1987 mean watertable was 49 mm lower than in the previous month, despite the above-normal 79.5 mm rain in July. This impact of vegetation was also indicated by the average 8 mm rise of the September 1986 watertable following harvest of the recharge area during August.

On average, the watertable declined over the three year study period. It averaged 1.41 m below ground level (BGL) in January 1986 and ranged between 1.10 and 1.73 m at the east side of the enclosure (near the center of the drainfield). In December 1988, the watertable was, on average, at a depth of 1.87 m BGL, ranging from 1.33 to 2.44 m. On both dates, the watertable was highest near the middle lateral. The decline in level over the three year period was greatest at the most upslope and downslope locations of the drainfield. It is unlikely that the lowering of the groundwater level was caused by the cultivation of the west half of the drainfield, since the direction of groundwater flow was from the northeast to the southwest (Sommerfeldt and MacKay 1982). However, some of the drawdown may have been due to the weedy vegetation, mainly annuals, that grew on the uncultivated drainfield area to the east of the plots.

The upslope and midslope interceptor drains were below or at the watertable throughout the monitoring period, whereas the downslope drain was at, but mainly above, the watertable or phreatic level (Fig. 2). However, the position of the drains relative to the watertable level did affect the configuration of the watertable hydrographs. They influenced the upslope watertable for a lateral distance of about 3.5 m, but their downslope effect was less distinct. Contrary to theoretical considerations (Donnan 1959), phreatic levels were always higher immediately downslope from each interceptor drain compared with immediately upslope of that drain. This was probably due to smearing of the downslope wall of the excavation trench which, unlike the upslope wall, did not collapse when the drains were installed.

Neutron moisture measurements

The relative volumetric soil-water content under Roamer alfalfa during the 1986 growing season varied most at the 0.23 m depth and least at the 1.07 m depth (Fig. 3). However, the water content at each monitoring site differed little

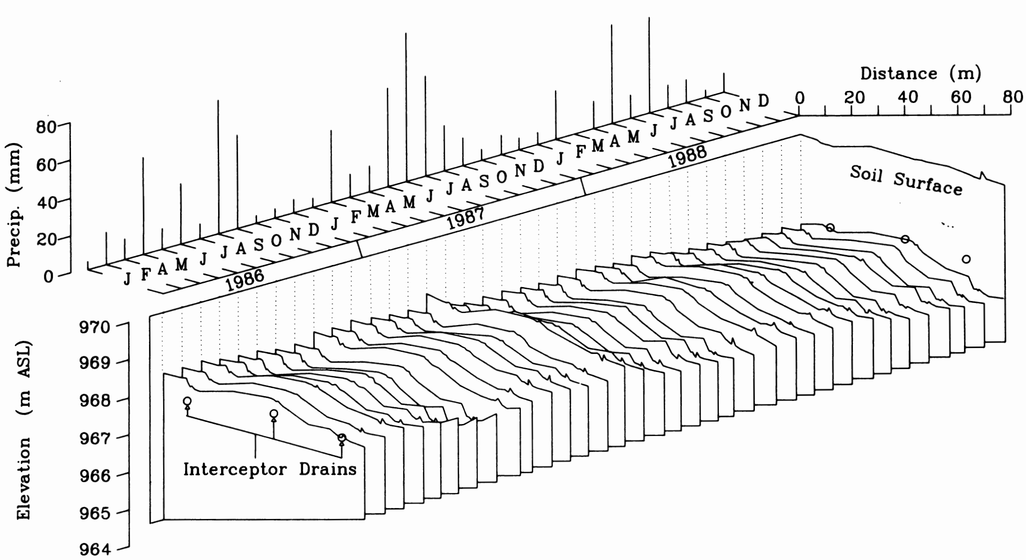

Fig. 2. Mean monthly precipitation and monthly watertable hydrographs for the years 1986-88. Data for March 1986, missing due to frozen observation wells; precipitation for that month was 14.9 mm.

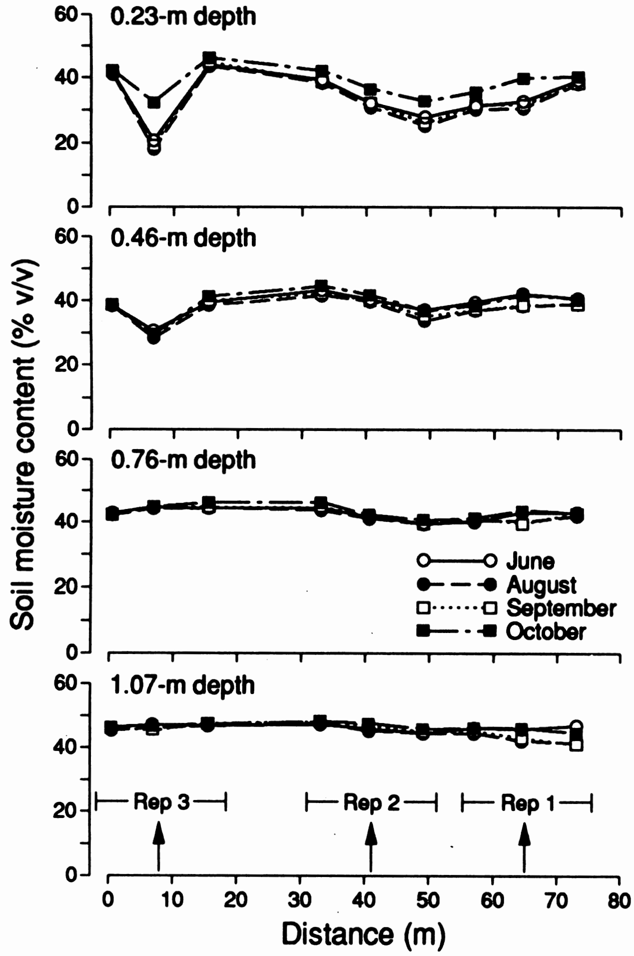

Fig. 3. Soil-water content under Roamer alfalfa at 0.23-m, 0.46-m, 0.76-m, and 1.07-m depth at three distances from each interceptor drain, 1986. Arrows indicate location of drains.

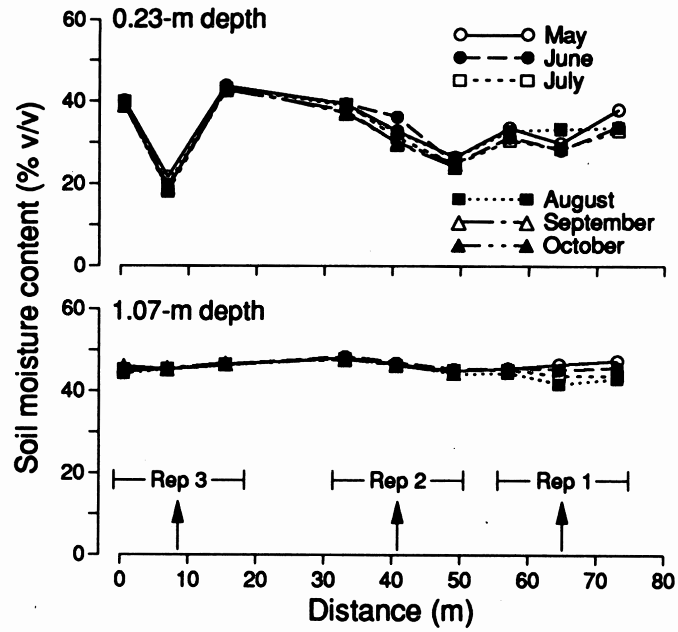

Fig. 4. Soil-water content under Roamer alfalfa at 0.23-m and 1.07-m depth at three distances from each interceptor drain, 1987. Arrows indicate location of drains.

throughout the season. Exceptions were the mean October measurements, where the overall increase in water content during that month was attributable to the near cessation of plant growth and the more than 50 mm precipitation (Fig. 2) in the previous month. The 1987 relative soil-water contents were generally similar to those of 1986 (Fig. 4). There was virtually no response of the soil-water content to the 126 mm of precipitation in June and July, probably because of high evapotranspiration rates. In 1988, the year of greatest drought, the soil-water content at all transect sites in the downslope half of the drainfield varied considerably at all depths, but particularly below the 0.23 m depth (Fig. 5). This coincided with the period of greatest decline and fluctuations in monthly watertable levels. These fluctuations in phreatic level and soil-water content were attributed firstly to reduced seepage rates because of the drought and higher than normal areal evapotranspiration, and secondly to enhanced soil-water withdrawal from below the 0.23 m depth by the standing crop on the drainfield. The latter contention was supported by the occurrence of roots below the level of the downslope drain in soil cores taken in the fall of 1988.

The general lack of variation in soil-water content per transect site in the first two years of the study suggests that the soil water was replenished mainly by capillary rise from the watertable. Withdrawal of soil water from below the 0.23 m depth commonly occurred in the downslope half of the drainfield after June 1988. In June 1988, the mean phreatic level for this portion of the drainfield was 1.94 m BGL compared with 2.16 m BGL in November 1988, when the decrease in soil water at the 0.46 m and lower depths was most conspicuous (Fig. 5). Assuming that the decrease in soil water at the 0.46 m depth commenced when the watertable was about halfway between the June and November levels (i.e. at 2.06 m BGL), then the height of capillary rise was at least 1.60 m. In April 1986, at the start of the second growing season of the alfalfa crop, the mean watertable for the same area stood at 1.38 m BGL implying that capillary rise likely reached the ground surface. Simulation of capillary rise from a phreatic level of 2.00 m showed that, at a pressure head of 60 kPa, a flux density of 5 mm•d^{-1} would reach the surface (Fig. 6). The 0.40 m difference between the extrapolated and simulated capillary rise may be due, in part, to desiccation cracks in the upper soil material and the fact that the simulation excludes water withdrawal by the standing (alfalfa) crop.

The relative soil-water regime for the 0.23 and 0.46 m depths showed variable but persistent effects of the interceptor drains (Figs. 3-5). The mean study-period water content at these and the 0.76 m depth varied significantly between the 1 m upslope (+1) and the 7 m upslope (+7) and 7 m downslope (-7) from-the-drainline locations in Replicates 2 and 3, but not in Replicate 1 (Table III). In addition, there were differences between locations and depths in the mean annual soil-water content that varied in significance from

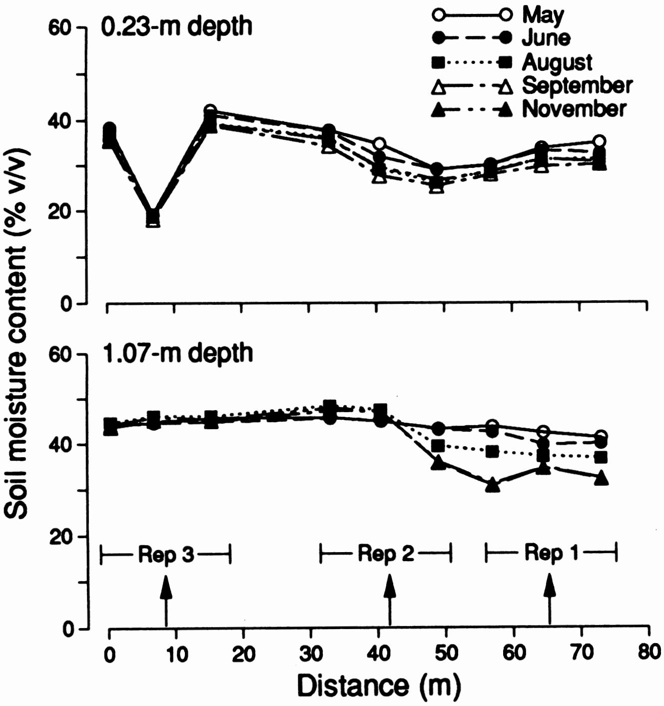

Fig. 5. Soil-water content under Roamer alfalfa at 0.23-m and 1.07-m depth at three distances from each interceptor drain, 1988. Arrows indicate location of drains.

year to year (results not shown). This variability between drainlines was attributed to the groundwater supply, which seeped mainly through the slightly dipping, fractured, upper bedrock (Miller 1989). The differences among replicates suggest that an active seepage locus was situated between the upslope and midslope interceptor drains.

Gravimetric soil-water measurements

The distribution of average soil-water content per 0.30 m of the total 1.50 m depth sampled in October 1988 showed a wide variation in water gradient and content across the plot area (Fig. 7). Water gradients were greatest in Rep. 3, which substantiated the large depletion of soil water shown in Figs. 3-5. Water contents were generally higher in the east half than in the west half of the plot area. Highest levels occurred in the southeastern quarter of Rep. 3, which tended to extend, at slightly lower levels, into the northeastern quarter of Rep. 2. This suggested the presence of a major seepage locus between these areas. Similarly, the isolated area of high water content in the southwestern quarter of Rep. 2 likely indicated the presence of a seepage channel.

In general, the lowest average soil-water contents were found along the western edge of the plot area. This was attributed to contributory drainage by the perforated collector drain because previous groundwater monitoring indicated that its impact extended into all second plots on the west side of the plot area. Within each replicate, the north-to-south water gradients generally reflected the effect of the interceptor drain located along the center axis of the replicate. This was indicated by the generally lower water gradients in the north than the south half of Reps. 2 and 3 and in the south compared with the north half of Rep. 1.

The soil-water content of the 0 to 0.60 m depth in the Roamer alfalfa plots was affected differently by the depth to phreatic level than was that below the 0.60 m depth (Fig. 8). The trend for the 0 to 0.60 m depth (Fig. 8a) was essentially linear, which was attributed to differential water withdrawal by the growing crop. Greater crop water use, as indicated by the better growth which was visible from year to year, had occurred on the downslope half of Reps. 1 and 2 and the upslope half of Rep. 3 than on their counterparts. This related to a deeper average watertable in areas with relatively good crop growth than in poorer growth areas. For instance, the mean monthly watertable during the 1988 growing season was at 1.90 m BGL in areas with better crop growth compared with 1.78 m BGL in poorer growth areas. This relationship between apparent crop growth and watertable depth is contrary to the findings of Benz et al. (1981) who reported higher yields of irrigated corn and sugar beets when the watertable was at 1.5 m than at greater depths. The main reason for better crop growth with deeper watertables in this study appears to be that the capillary rise of saline groundwater (EC of 10 $dS \bullet m^{-1}$) does not reach the soil surface.

A non-linear trend in soil-water content was suggested for the 0.60 to 1.50 m soil depth (Fig. 8b). It can be visualized as a horizontal line for groundwater depths less than about 1.8 m and a downward sloping line for greater depths, approxi-

Table III: Means and standard errors of relative soil-water content over the study period at specified soil depths and distances from interceptor drain for each replicate

Depth (m)	n	Rep. 1 +7†	Rep. 1 +1†	Rep. 1 -7‡	Rep. 2 +7	Rep. 2 +1	Rep. 2 -7	Rep. 3 +7	Rep. 3 +1	Rep. 3 -7
0.23	29	30.07 ± 0.62	31.19±0.79	34.27*±0.90	37.47**±0.59	32.47±0.62	26.55**±0.46	38.18**±0.80	20.23±0.69	41.83**±0.83
0.46	29	35.93*±0.72	38.44±0.71	37.58 ±0.71	41.38**±0.58	38.62±0.53	34.77**±0.50	36.68**±0.65	29.61±0.49	37.97**±0.64
0.76	29	38.31 ± 0.89	39.35±0.84	40.17 ±0.88	42.58**±0.65	39.52±0.56	37.61* ±0.59	39.74**±0.75	42.91±0.73	42.83 ±0.75
1.07	29	42.53 ±1.00	41.57±0.93	40.84 ±1.07	45.90 ±0.69	44.65±0.65	42.87 ±0.69	43.62 ±0.75	43.81±0.75	44.82 ±0.78

†Indicates distance (m) upslope from drainline.

‡Indicates distance (m) downslope from drainline.

*,**Means are significantly different from +1 location at P < 0.05 and P < 0.01, respectively (t-test).

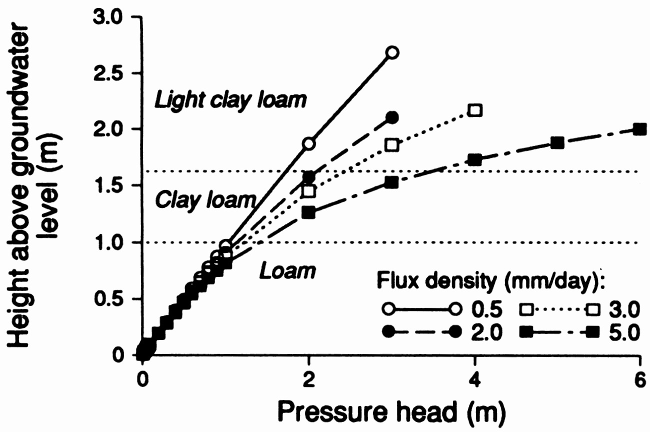

Fig. 6. CAPSEV simulation of the relation between height of capillary rise above the groundwater level at 2.00-m depth and pressure head of the capillary fluxes in the soil studied.

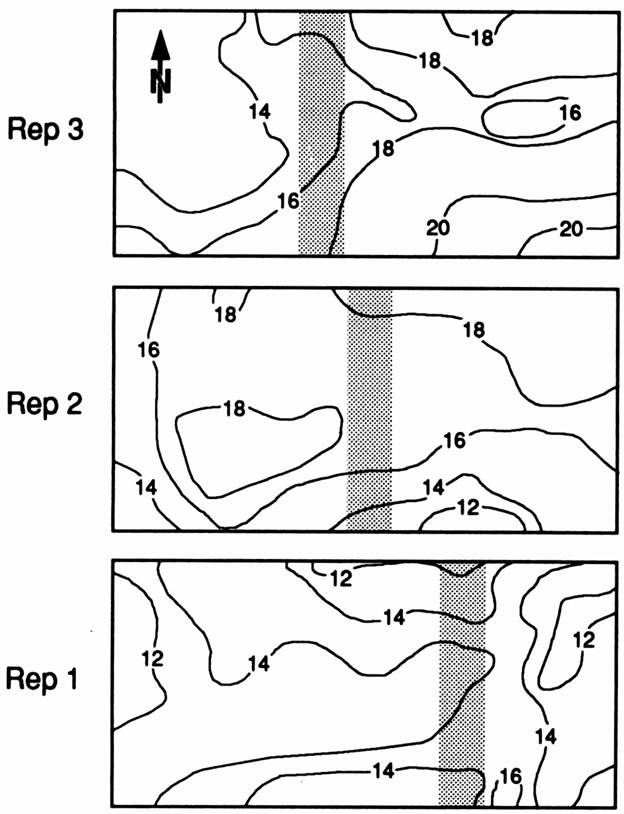

Fig. 7. Spatial distribution of average soil-water content (% by weight) per 0.3 m of the 1.5-m sampling depth in the plot area on October 7, 1988.
Shaded areas indicate locations of Roamer alfalfa plots.

mately representing mainly saturated and partly unsaturated conditions above the watertable, respectively. The breakpoint at about 1.8 m depth lends additional support for a 1.8 m or greater height of capillary rise for this soil. This depth corresponds with the 1.8 m drain depth generally recom-

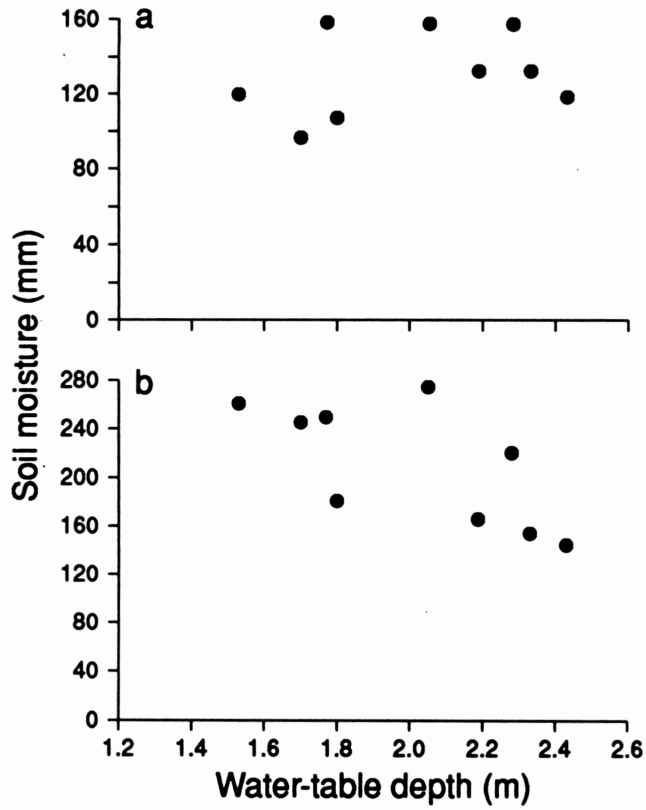

Fig. 8. Relationship between watertable depth and soil-water content under Roamer alfalfa in a) 0- to 0.60-m and b) 0.60- to 1.50-m depth.

mended in arid areas for control of saline groundwater during the fallow season in irrigated soils with intermediate texture (FAO 1980). By implication, the drain depths used in this study would be inadequate for salinity control. This is supported by the observed poor crop growth at the four sampling locations with groundwater at <1.8 m; namely, the 7 and 1 m upslope from the drain sites in Rep. 2 and the 7 m downslope and 1 m upslope sites in Rep. 3. On the other hand, the half of each replicate with visibly good crop growth suggests that the drain depths were satisfactory. In view of the dependence of crop performance on soil salinity, particularly under dryland conditions, the suitability of the drain depths used needs to be substantiated by the salinity distribution and crop performance on the drainfield.

CONCLUSIONS

Subsurface interception drainage significantly affected the soil-water regime at different distances from the drains. The impact varied according to interceptor drain, due to the seeping nature of the groundwater discharge. As a consequence, the spatial distribution of soil-water content at any time did not clearly reflect the location of the interceptor drains within the drainfield, although it did indicate probable loci of sustained seepage.

The subsurface interceptor drains had a pronounced upslope effect over a distance of about 4 m on the phreatic level, but their downslope impact was less distinct. Phreatic levels, in turn, affected the soil-water regime, owing to capillary action. A greater than 1.60 m capillary rise of water from the watertable was indicated by the soil-water contents across the drainfield compared with a simulated rise of about 2.00 m. This supported the 1.80 m drain depth recommended in arid areas for control of saline groundwater in soils of intermediate texture. Subsurface interception drainage improved trafficability by decreasing soil-water content and lowering the watertable, and prevented the capillary rise of saline groundwater to the land surface at least in part of the drainfield.

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