Water and Salt Distribution in a Field Irrigated with Marginal Water under High Water Table Conditions

M. Ben-Hur, F. H. Li, R. Keren, I. Ravina, and G. Shalit

ABSTRACT

Development of an impermeable layer at some depth beneath the soil surface and the presence of a high groundwater level are common phenomena in the Yizre’el Valley, Israel. The main objective of this study was to determine the salt and water distributions and salt leaching in a field irrigated by sprinklers, under nons isotropic and high groundwater level conditions. A field experiment was conducted in a cornfield (Zea mays L.) on a Vertisol (Typic Chromoxerets) with subsurface drains. The electrical conductivity (EC) of the irrigation water was 2.5 dS m$^{-1}$. The variations in water table level, in EC of soil solution and soil saturation paste, and in gravimetric water content along the field were determined at different times. Likewise, corn yield from various sites across the field was determined at the end of the summer season (August). The water table level increased sharply in the winter to 49.5 m, and then decreased continuously in the summer despite the irrigation. The EC increased in the downhill direction, more sharply in the deeper soil layers. In the upper part of the field, the average EC in saturation paste in the 0- to 1.2-m soil layer was 1.1 dS m$^{-1}$ in March (end of the rainfall season) and 2.1 dS m$^{-1}$ in August. Conversely, in the lower part of the field, the ECs in March and August were 4.4 and 3.7 dS m$^{-1}$, respectively. A linear reduction of the corn yield with increasing EC was observed. The relatively low level of the groundwater at the upper part of the field allowed vertical salt leaching by the rainfall. Conversely, the rise of the saline (EC = 20 dS m$^{-1}$) groundwater in the lower part of the field in the winter with lateral salt movement increased the soil EC. Decline of the water table in the latter part of the summer allowed vertical leaching of salt by the irrigation water.

Arid and semiarid regions are characterized by long, dry summers and short rainy winters. Therefore, agricultural production in these regions relies mainly on irrigation. The soil solution in irrigated fields is frequently more saline than the irrigation waters because of evapotranspiration that leaves the salts from the irrigation water in the soil and the dissolution of some soil minerals (Rhoades et al., 1973). Consequently, irrigation may increase the salinity and the sodicity of the soil profile to a point at which plant growth is reduced (Maas and Hoffman, 1977) and the soil structure is damaged (Ben-Hur et al., 1998).

Conventional sources of good quality water in arid and semiarid regions are scarce, which has led to increased use of marginal water (saline waters and treated sewage effluent) for irrigation (Bresler et al., 1982; Feigin et al., 1991). This enhances the salinization of the irrigated lands in these regions. To avoid the accumulation of salt in the soil, salt leaching from the root zone should be conducted. In regions where the rainfall is low, a leaching fraction (the fraction of applied water that appears as drainage water) is added to the irrigation water to hold the salt concentration in the soil below a specific value (Rhoades et al., 1973). In contrast, in regions where the rainfall is relatively high, the wet season rainfall can ensure leaching of the salt.

The water percolating below the root zone moves downward to the groundwater and may cause the water table to rise. As the water table approaches the soil surface, poor soil aeration and/or high salinity in the root zone may reduce crop yields. Consequently, installation of a subsurface drainage system, to keep the water table from rising and to allow salt leaching, is commonly considered to be essential for long-term productivity (Bradford and Letey, 1992).

Under steady-state and isotropic conditions, the salt distribution in a field is independent of landscape position and time. Many studies (e.g., Beven and Germann, 1981; Meyer et al., 1990; Bradford and Letey, 1992; Thorburn et al., 1995) have described the water and salt movements and distributions under these conditions.

In many cases, particularly in valleys, such as the Imperial Valley in California (Grismer and Tod, 1991) and the Yizre’el Valley in Israel (Shalit et al., 1998), the top soil is a Vertisol. In this soil, development of a compacted, low-permeability layer at some depth beneath the soil surface, which, in turn, causes a high water table, is a common phenomenon (Yaalon and Kalmar, 1978; Gafni and Salinger, 1992; Ben-Hur et al., 1998). Under these conditions and under irrigation with marginal water, the salt content in the field can change with time: accumulation of salt in the soil during the dry season and salt leaching in the rainy season. Moreover, the salt distribution in the field may depend on the local topography because of lateral flows of groundwater and variations along the field in its depth beneath the soil surface. Water and salt distributions in a field receiving sprinkler irrigation under nons isotropic and non-steady-state conditions have elicited less documentation.

A Vertisol is defined as a deep (>50-cm depth) soil containing at least 30% clay in all horizons and in which the dominant clay (>50%) is smectite (FAO, 1990). Such a soil swells when wet and develops cracks when dry (Yaalon and Kalmar, 1978).

The Yizre’el Valley can be used as a case study for high water table level and nons isotropic conditions. This valley is the largest in Israel, located in Lower Galilee in northern Israel, and is known for its fertile soil. The area of this valley is 250 km$^2$, of which 200 km$^2$ are under cultivation and 140 km$^2$ under irrigation, mostly...
with marginal water. The farmers’ practice to prevent salinization in this region is to satisfy the crop water demand by means of irrigation in the summer and to rely on the winter rainfall for salt leaching. The average annual rainfall in this region is 500 mm, concentrated into ~4 mo in the winter.

A dense, usually saline soil layer was found at depths of 1.5 to 5 m in the Yizre’el Valley (I. Ravina, 1990, personal communication), while the hydraulic conductivity of this layer is in the order of $10^{-9}$ cm s$^{-1}$ (Gafni and Salinger, 1992). In many locations in the Yizre’el Valley, there are two different aquifers (Gafni and Salinger, 1990; Schein and Livne, 1997): (i) a shallow (above the low-permeability layer), perched aquifer and (ii) a deep, coarse-textured aquifer, which is confined by the compacted, low-permeability layer overlying it. The latter aquifer is liable to artesian pressure (Shalit et al., 1998).

Significant salinity problems, combined with crop yield reductions, have been observed in irrigated lands in the Yizre’el Valley. It is hypothesized that these salinity problems and yield reductions are mainly related to high water table levels and to an improper salt leaching practice.

The objectives of our study were (i) to determine the salt and water distributions and their effects on corn yield in a field irrigated with marginal water by sprinklers under nonisotropic conditions and (ii) to study the salt leaching in a field under high water table conditions.

**MATERIALS AND METHODS**

The experiment was conducted in a tilled field located in the western part of the Yizre’el Valley, Israel. The field had a fairly constant gradient of 1% toward a small stream in the south (Fig. 1). The soil in the experimental field was a Vertisol, and the soil subgroup, according to U.S. soil taxonomy is Typic Chromoxerets (Soil Survey Staff, 1975). The soil texture was 620 g kg$^{-1}$ clay, 300 g kg$^{-1}$ silt, and 80 g kg$^{-1}$ sand, the dominant clay being montmorillonite. The soil contained 66 g kg$^{-1}$ CaCO$_3$ and 39 g kg$^{-1}$ organic matter and had a cation-exchange capacity of 54 cmol$_c$ kg$^{-1}$.

Subsurface drains had been installed in the experimental field in 1991, at depths of 0.9 and 1.9 m (Fig. 1): they were ~200 m long and spaced 30 m apart. In the fall of 1993, five clusters of piezometers were installed along a cross section of the field at depths ranging from 0.5 to 5 m (Fig. 1). All the piezometers were monitored for water table level, usually twice a week.

In the fall of 1994, five clusters of ceramic suction cups were installed along a cross section of the field (Fig. 1) to depths of 0.6, 0.9, 1.2, and 1.8 m at each site. Water samples were collected from all the suction cups, usually once a week, from December 1994 until middle of May 1995, and EC was determined in these water samples.

In the summer of 1994, cotton (*Gossypium hirsutum* L.) was grown in the experimental field. In the spring of 1995, the field was plowed, disked, and leveled with a roller to provide a smooth seedbed. Forage corn was planted on 14 Mar. 1995 with a population of ~60 000 plants ha$^{-1}$. The field was routinely irrigated with a linear moving sprinkler irrigation system with a lateral discharge of 850 L m$^{-1}$ h$^{-1}$. The irrigation system was equipped with Nelson (Walla Walla, WA) spray nozzles spaced 2 m apart at heights of 1.6 and 1.8 m, alternately, above the soil surface. The irrigation was started on 1 May 1995. The total irrigation application was 373 mm, and the irrigation application at each event ranged from 35 to 65 mm. The EC of the irrigation water was 2.5 dS m$^{-1}$ and the Na adsorption ratio (SAR) was 6 (mmol L$^{-1}$)$^{0.5}$. The soil was fertilized with NH$_4$NO$_3$ (200 kg N ha$^{-1}$) applied with the irrigation water.

Soil samples were taken at 5-m intervals along a cross section of the field (Fig. 1), to a depth of 1.2 m at intervals of 0.3 m. The soil samples were taken on 20 Mar. 1995 and on 25 Aug. 1995. Electrical conductivity in saturated soil paste was determined in the soil samples on both sampling dates, while gravimetric water content in the soil was determined only in the later soil sampling.

![Fig. 1. Schematic layout of the studied field.](image-url)
Corn yield was determined for each sampling site (Fig. 1) at the end of the growing season. At each sampling site, nine plants were cut 3 cm above the soil surface, and the cob and canopy weights of each plant were determined after 48 h of drying at 60°C.

The significance of differences (α = 0.05) between the various studied parameters and of the regressions were determined by means of Student’s t test.

RESULTS

A rainfall depth of each rainstorm during the winter of 1994-1995 and the irrigation application of each event during summer of 1995 are presented in Fig. 2A. The total rainfall in this winter was 618 mm, which is ≈24% more than the average annual rainfall in this region. The first rainstorm was on 9 Oct. 1994 and the last on 3 Apr. 1995, 20 d after the corn sowing.

The accumulation of rainfall and irrigation had an effect on the water table level, as presented in Fig. 2B, which shows piezometer cluster K readings during the winter of 1994-1995 and summer of 1995. The other piezometer clusters showed, in general, the same trend of water table levels as was observed in cluster K; therefore, they are not presented.

The water table levels at the 5-m-depth piezometer were higher than those at the 1.5-m-depth piezometer for any given sampling date from 1 Jan. 1995 through 1 Aug. 1995 (Fig. 2B). This may indicate the existence of two aquifers in the studied field: an upper, perched aquifer and a lower aquifer, which is under artesian pressure most of the time. Gafni and Salinger (1992) reached the same conclusion in their study in the Yizre’el Valley.

The water table at both piezometers was low until 1 Dec. 1994, in spite of the 255 mm of rain that fell during this time (Fig. 2). The water table level increased sharply in both piezometers on 1 Jan. 1995, when an additional 131 mm of rain precipitated. From this date, the water table level rose gradually up to a maximum on 15 Feb. 1995 and then it fell, in general, with time to <48.7 m in fall 1995. The high water table at the 1.5-m piezometer in the winter (Fig. 1) indicates the low efficiency of the subsurface drainage system in preventing the winter rise of the perched groundwater level.

In the summer, the water table level in the two piezometers decreased continuously despite the 373 mm of irrigation (Fig. 2). After the last rainstorm (1 Apr. 1995), the water table levels at the 1.5- and 5-m piezometers were 49.26 and 49.64 m above sea level, respectively, and after the end of the irrigation season (1 Aug. 1995), they were 48.87 and 48.95 m, respectively (Fig. 2). In the summer, the decline of the perched water level was mainly the result of the high evapotranspiration and the water drainage.

The water table depths beneath the soil surface on 12 Feb. 1995 and 23 Apr. 1995, as determined by means of the piezometers at 1.5-m depth in the various clusters along the field, and their regression lines are presented.
Fig. 3. Water table depth beneath soil surface at two sampling dates as functions of the downhill distance.

The regression lines represent the gradient of the perched aquifer relative to the soil surface. The water table depth beneath the soil surface decreased in the downhill direction on both dates. These decreases were because of the differences between the gradients of the soil surface of the field and of the water table. Moreover, the decrease of the water table depth with downhill distance was steeper on 23 Apr. 1995 than on 12 Feb. 1995, which indicates that the drainage of the perched aquifer was faster at the uphill side of the field than at the downhill side.

The residual, gravimetric soil moisture contents at various sampling sites along the field and at various soil depths at the end of the corn growing season (25 Aug. 1995) are presented in Fig. 4, as a function of the distance of the sampling site from the uphill end of the field. No significant trend of the soil moisture along the field was observed for the various soil depths (Fig. 4). The variation of the soil moisture values along the field, as indicated by the coefficient of variance (CV), was relatively low (<0.23). The highest CV value was in the top layer (0-0.3 m), a layer that was exposed to the atmosphere, and the lowest CV value (0.05) was in the 0.3- to 0.6-m layer, in which the main part of the corn roots developed (Shalhevet et al., 1981).

The gravimetric field capacity of a Vertisol from the Yizre’el Valley region is ~34% (O. Hadas, 1999, personal communication). The average soil water contents in the 0- to 0.3-, 0.3- to 0.6-, 0.6- to 0.9-, and 0.9- to 1.2-m soil layers were 19.5, 20.5, 21.9, and 24.5%, respectively (Fig. 4); all of which were below the field capacity of the soil. These results suggest that the corn roots dried the soil profile down to 1.2-m depth by the end of the growing season.

The EC values in saturated paste of soil samples from the various sites along the field and at various depths, on two sampling dates, are presented in Fig. 5, as functions of the distance of the sampling site from the uphill end towards the downhill end. On both sampling dates and at all soil depths, except in the 0- to 0.3-m soil layer at the end of the irrigation season (25 Aug. 1995), the EC values increased in general with the distance from the upper end. This increase of the EC was more pronounced in the downhill part of the field and in the deeper soil layers.

The EC results (Fig. 5) indicated that the field could be considered as two main parts, distinguished by their EC values: (i) the upper part, from 0 to 55 m downhill, in which the EC values were low and (ii) the lower part, from 55 to 120 m, where the EC values were high. The average values of EC for each part of the field at different soil depths and on the two sampling dates in 1995 are presented in Table 1. Except for the 0- to 0.3-m layer in the August sampling, the average EC values in the lower part of the field were significantly higher than those in the upper part, for each soil depth and sampling date (Table 1). Likewise, in the upper part of the field, the average EC values were significantly higher in August (the end of the irrigation season) than in March (approximately the end of the rainy season) for each soil depth. In contrast, in the lower part of the field, the average EC value at the end of the winter was higher, but not statistically significantly so, than at the end of the irrigation season, for each soil layer except the top one (Table 1).

Electrical conductivity values of soil solution from
four different soil depths at five sites along the field (Fig. 1) that were sampled from 12 Dec. 1994 until 5 May 1995 (the beginning of the irrigation season) by means of extraction cups are presented in Fig. 6. The variation of the EC values with time was relatively low (CV <0.32) for all the sampling sites and soil depths. Correlation of the EC values vs. the sampling dates showed no significant trend of the EC with time at any of the sampling sites. The fluctuations of the EC with time probably resulted from fluctuations in the rainstorm depths and intensities.

The differences in EC values among the sampling sites and among depths at some sites were significant (Fig. 6). In the most uphill site (Site 1), the EC value increased with soil depth on each sampling date; the average EC values for 0.6- to 0.9-, 1.2-, and 1.8-m soil depths were 2.8, 4.8, 6.3, and 9.9 dS m⁻¹, respectively. At Site 2, the EC values were similar at the 1.2- and 1.8-m soil depths (15.9 dS m⁻¹, on average), where they were significantly higher than those at 0.6 and 0.9 m. The EC values at 0.9 m at this site were higher than those at 0.6 m for each sampling date, and the average values of the EC for each depth were 9.8 and 6.5 dS m⁻¹, respectively. At Site 3, as at Site 2, the EC values at 1.2 and 1.8 m were similar (17.3 dS m⁻¹ on average) and significantly higher than those at 0.9 and 0.6 m. However, at this site, the EC values at 0.6 and 0.9 m were similar to one another (8.4 dS m⁻¹ on average). At Site 4, the EC values at 1.8, 1.2, and 0.9 m were similar to one another (21.9 dS m⁻¹ on average) and higher than that at 0.6 m. At Site 5, the EC values at all depths were similar, and the average was 19.9 dS m⁻¹. The results presented in Fig. 6 showed the same trends of EC along the field and with depth as those presented in Fig. 5. The EC values increased with increasing distance from the uphill end toward the drain-

Table 1. Average electrical conductivity in soil saturated paste for the upper and lower field parts at different soil depths and two sampling dates and the significance of the differences between the field parts (BP) and between the seasons (BS).

<table>
<thead>
<tr>
<th>Soil depth</th>
<th>Upper part (0-55 m)</th>
<th>Lower part (55-120 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Significance</td>
</tr>
<tr>
<td>0-0.3 m</td>
<td>0.71</td>
<td>a‡</td>
</tr>
<tr>
<td>0.3-0.6 m</td>
<td>0.85</td>
<td>a a</td>
</tr>
<tr>
<td>0.6-0.9 m</td>
<td>1.08</td>
<td>a a</td>
</tr>
<tr>
<td>0.9-1.2 m</td>
<td>1.56</td>
<td>a a</td>
</tr>
</tbody>
</table>

‡ Different letters indicate significant ($\alpha = 0.05$) differences between the upper and lower parts of the field for the same season.

§ Different letters indicate significant ($\alpha = 0.05$) differences between the seasons for the same field part.
on the corn yield of the salt distribution in the experimental field; a significant linear reduction of the corn yield with increasing EC was found. In this regression, no salinity threshold was considered. The slopes of these linear regressions, which represent the productivity decrease of the crop (Bresler et al., 1982), were 2.7% for the total yield and 8.7% for the cob yield.

**DISCUSSION**

Irrigation with marginal water and rise of saline groundwater close to the upper soil layer can increase the salinity of the soil. In opposition to this, leaching of salts during the rainy season could decrease the salt concentration in the soil. Under rainfall and sprinkler conditions and with no artificial drainage, the salt leaching in soil is, in general, vertical. However, because of the impermeable layer beneath the soil and the high water table in the Yizre’el Valley, vertical salt leaching could be limited.

The EC values at various soil depths, at sites along the experimental field (Fig. 5 and 6) indicated that there was a trend of salinity in the field. It increased in the downhill direction and with soil depth. Likewise, the salinity in the soil changed with the seasons (after the rainfall and the irrigation seasons) and this change differed between the upper and lower parts of the field (Table 1).

Two main processes can account for this salt distribution in the field:

1. The gradient of the perched groundwater level in the experimental field was, in general, 0.1% (Shalit et al., 1998). This led to a lateral, downhill flow of groundwater toward the main stream at the lowest point of the field (Fig. 1). On the basis of measurements in 14 randomly spaced wells and two 4-m piezometers in the Me Ammi area in the Yizre’el Valley, Gafni and Salinger (1992) also concluded that the perched groundwater flows laterally toward the main stream in the region, which is the

![Graph showing electrical conductivity of soil solution extract at various soil depths and sites along the field as functions of the sampling date.](image)

**Fig. 6.** Electrical conductivity of soil solution extract at various soil depths and sites along the field as functions of the sampling date.

High electrolyte concentration in the soil solution reduced the corn yield. The average dry matter of the total yield (canopy + cobs) and of cobs only for the nine plants, at each sampling site as a function of the average EC in soil saturation paste for the 0- to 1.2-m soil layer is presented in Fig. 7. These results represent the effect

![Graph showing average dry matter content of the total corn yield (canopy + cobs) and of cobs only at each sampling site as functions of the average electrical conductivity in saturated soil paste.](image)

**Fig. 7.** The average dry matter content of the total corn yield (canopy + cobs) and of cobs only at each sampling site as functions of the average electrical conductivity in saturated soil paste.
regional drainage base. The lateral flow of the perched groundwater could leach the salt laterally and concentrate it in the soil near the drainage base. The high EC values in the lower part of the field (Fig. 5 and 6) are most likely related to this lateral leaching of the salt.

2. The depth from the soil surface to the perched water table decreased in the downhill direction (Fig. 3). This decrease of the water table depth was probably the main cause for the differences in the salt distributions in the field between the ends of the irrigation and of the rainfall seasons (Table 1) as described below.

In order to determine the factors that affected the salt distribution in the field in the two seasons, the total amounts of salt in the field in the 0- to 1.2-m soil profile were calculated for each part of the field and for each of the two seasons and are given in Table 2. This calculation took into account the soil bulk density, the water content in the soil paste, and the salt concentration (SC) in the saturated soil paste extract, as described in Eq. [1] (U.S. Salinity Laboratory Staff, 1954).

\[
SC = 10 \text{ EC} \quad [1]
\]

in which SC is in mmol \(\cdot\) L\(^{-1}\) and EC in dS \(\cdot\) m\(^{-1}\).

The salt balance in the field between the seasons could be described by Eq. [2]

\[
\Delta S = S_f + S_i - S_t \quad [2]
\]

in which \(S\) is the salt content and the subscripts indicate salt content in the field in 0- to 1.2-m soil profile after the rainfall season (March) and the irrigation season (August) (Table 2), and in the application of 373 mm of irrigation water, respectively.

Equation [2] indicates that:

1. If \(\Delta S = 0\), no salt leaching below 1.2-m soil depth occurred, and no other salt source than the irrigation water contributed salt to the soil during the irrigation season.
2. If \(\Delta S > 0\), some salt was leached below the 1.2-m soil depth during the irrigation season.
3. If \(\Delta S < 0\), an additional salt source, besides the irrigation water added salt to the field in the 0-1.2 m soil profile during the irrigation season.

In the winter, the low level of the groundwater relative to the soil surface at the upper part of the field (Fig. 3) allowed vertical salt leaching by the rainwater. Thus, the EC values at the end of the rainy season were low, 0.74 dS m\(^{-1}\) in the top layer and 1.6 dS m\(^{-1}\) in the 0.9- to 1.2-m layer (Table 1). The EC in saturation paste of Vertisol from Yizre'el Valley under rainfed conditions has been reported as 0.6 dS m\(^{-1}\) (Ben-Hur et al., 1998). In contrast, in the summer, in this part of the field, irrigation with water having an EC of 2.5 dS m\(^{-1}\), combined with the high evapotranspiration, significantly increased the EC in the soil profile to 1.9 to 2.4 dS m\(^{-1}\). In this case, \(\Delta S = -42871\) mol \(\cdot\) ha\(^{-1}\), which indicates that 42871 mol \(\cdot\) ha\(^{-1}\) of salt was added to the upper part of the field in addition to the contribution of the irrigation water.

Table 2. Total salt content in the two parts of the field and the two sampling dates.

<table>
<thead>
<tr>
<th>Salt content</th>
<th>Upper part</th>
<th>Lower part</th>
</tr>
</thead>
<tbody>
<tr>
<td>mol, ha(^{-1})</td>
<td>218 975</td>
<td>617 413</td>
</tr>
<tr>
<td></td>
<td>355 096</td>
<td>627 252</td>
</tr>
</tbody>
</table>

From Fig. 3, it can be concluded that the water samples that were extracted by means of suction cups at 1.2- and 1.8-m depths (Fig. 6) were, in general, from the groundwater. The EC values of these water samples (Fig. 6) indicated that the groundwater in the experimental field was saline. The EC at the upper site (Site 1) was 6.3 to 9.9 dS m\(^{-1}\) and that at the lower site (Site 5) was 19.9 dS m\(^{-1}\). Under these conditions, the addition of 42 871 mol \(\cdot\) ha\(^{-1}\) of salt to the soil in the upper part of the field during the irrigation season was probably a result of capillary movement of the saline, perched groundwater during the summer, which would lead to an accumulation of salt in the 0- to 1.2-m soil layer.

In contrast, in the lower part of the field, the winter rise of the perched, saline (EC=20 dS m\(^{-1}\)) groundwater close to the soil surface salinized the soil profile. Moreover, this high water table limited the vertical leaching of the salt by the rainwater. Consequently, the salt concentration in the 0.3- to 1.2-m soil layer was high in the winter (Table 1). In this part of the field, \(\Delta S = 83411\) mol \(\cdot\) ha\(^{-1}\). Decline of the water table level in the summer (Fig. 2) allowed vertical leaching of the salt (83 411 mol \(\cdot\) ha\(^{-1}\)) from the soil in the lower part of the field by the irrigation water, which had an EC of 2.5 dS m\(^{-1}\). As a result, the EC in the soil profile down to 1.2 m in the lower part of the field was, in general, lower at the end of the summer than at the end of the winter (Table 1).

The productivity decrease of the forage corn (total yield) as the EC of the soil saturated paste increased under steady-state conditions has been reported as 7.4% (Carter, 1981). This decrease is almost three times greater than that found in our study (Fig. 7). The EC values in the soil solution shown in Fig. 7 were calculated as average values for the 0- to 1.2-m soil layer. Thus, the low productivity decrease of corn found in our study was probably a result of the relatively low EC values in the upper soil layers (0-0.9 m), which allowed the development of the corn roots in these layers. However, the low water content in the 0.9- to 1.2-m soil layer (Fig. 4) indicated that some root development of the corn took place in this layer. In any case, the corn yield reduction in the experimental field indicated that the salt leaching in the lower part of the field during the summer was insufficient. It is most likely that an increase in the leaching fraction of the summer irrigation in the lower part of the field would prevent the yield reduction as long as the water table did not prevent salt leaching and plant development.

It can be concluded from this study that development of a compacted, low-permeability layer at some depth beneath the soil surface in the Yizre'el Valley led to a
rise of the perched aquifer level during the rainy season. Downhill lateral flow of the perched groundwater most likely leached the salt laterally and increased its concentration in the downhill part of the field. In irrigated areas where the water table depth beneath the soil surface is relatively large (=1.5 m), the main sources of the salt in the soil profile at the end of the irrigation season could be the high salt content of the irrigation water and upward capillary movement of the saline groundwater. However, a relatively high rainfall (618 mm) in the winter could leach the excess salt from the soil profile (0–1.2 m). In contrast, in an area where the water table rises close to the soil surface during the rainy season and the salt concentration in groundwater is high (EC =20 dS m$^{-1}$), the rise of the groundwater salinized the soil profile and limited the vertical leaching of the salt by the rainwater. Thus, in this case, the leaching of the salt from the soil profile depends mainly on irrigation in the summer. However, management plans should ensure that irrigation with a high leaching fraction would not raise the water table to a level at which it would prevent vertical salt leaching.

REFERENCES


