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TRICKLE IRRIGATION SOIL WATER POTENTIAL AS INFLUENCED BY MANAGEMENT OF HIGHLY SALINE WATER

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ABSTRACT

Although trickle irrigation offers the possibility of obtaining comparatively good yields when nontoxic highly saline water is used for irrigation, the subsequent accumulation of salts in the root zone is a potential hazard that should not be disregarded.

The objective of this investigation was to determine experimentally the soil water potential and salt patterns in uniform soil profiles as a result of four different water management treatments. Under these treatments cherry tomato plants were irrigated (a) daily with a volume of water equal to that used by the plant on the previous day, (b) every other day with volumes of water equal, (c) below, and (d) above the water evapotranspired.

In general, the soil water potential decreased in the soil profile, as a result of salt accumulation, with increased distance from the trickle source. In the profiles where the wetting fronts reached the mid-region between the emitters much lower soil water potentials were measured near the soil surface. The highest salt concentration occurred in the profiles irrigated with volumes of water below that evapotranspired by the tomato plants, indicating the importance of avoiding under irrigation whenever highly saline water is used with trickle irrigation. Higher soil water potentials and higher yields resulted from irrigating with volumes above the evapotranspiration.

INTRODUCTION

In trickle irrigation water is slowly applied to the soil surface from a point source and distributed within the soil profile in response to the existing hydraulic potential gradients at a rate which is affected by the flow properties of the soil. Nontoxic highly saline water has been reported to have an agricultural potential when managing irrigation in such a manner that high matric potential is maintained within the root zone, thereby counteracting the osmotic effects of the salts contained in the irrigation water (Goldberg and Shmueli 1970, Bernstein and Francois 1973). Nevertheless, salts in the irrigation water and those initially contained in the soil profile are displaced to the periphery of the wetted portion of the soil profile. The resulting accumulation of salts presents a hazard to crops particularly in areas where the natural precipitation is not sufficient to leach the accumulated solutes to deeper portions of the profile. This concentration of salts may occur not only as a consequence of applying highly saline water but also as a result of relatively long term accumulation of salts carried with irrigation waters of lower salinity hazard. Field observations on salt accumulation in soil profiles where highly saline water was applied by means of trickle irrigation have been previously reported (Goldberg et al. 1971b; Goldberg and Shmueli 1970). Emitter spacing and discharge rates appear to affect the accumulation of salt and distribution of water and fertilizer (Goldberg et al. 1971a).

The purpose of this investigation was to determine experimentally the salt accumulation and the resulting soil water potential patterns in

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uniform soil profiles as a consequence of four different water management treatments.

Experimental

The experiment consisted of the following four water management treatments with two replications: Treatment A, daily water application, at a rate of 0.3 liters per hour, of a volume equal to the volume of water evapotranspired the previous day. Treatment B, alternate-day water application, at a rate of 2.0 liters per hour, of a volume equal to the volume of water evapotranspired the previous two days. Treatment C, alternate-day water application, at a rate of 2.0 liters per hour, of a volume approximately equal to 87 percent of the water evapotranspired the previous day. Treatment D, alternate day water application, at a rate of 2.0 liters per hour, of a volume approximately equal to 1.20 times the water evapotranspired the previous day.

For the four treatments with two replications, eight wooden lysimeters were constructed with inside dimensions of 122 cm in height, 122 cm in width, and 21 cm in thickness. Each lysimeter was filled with a loamy sand soil and carefully compacted to a bulk density of 1.45 ± 0.03 g/cc.

To determine the amount of water applied and used by the plants, the lysimeters were operated similarly to that reported by Hanks and Shawcroft (1965).

The experiment was conducted in a greenhouse, where cooled air was automatically circulated whenever the air temperature reached 30.5°C.

Three 5-cm-high cherry tomato plants of the Early Salad variety were planted at each end of each lysimeter. After the plants reached a height of about 45 cm, a plant from each group was removed leaving the two healthiest plants at each end. The plants were used to extract water from the soil profile to increase the salt accumulation by successive irrigations rather than to study the plant response to this salt accumulation.

Water containing $CaCl_2$, with an electrical conductivity of 5.5 mmhos/cm or −1.6 bars osmotic potential, was applied from an emitter located at the base of each group of plants and 1.0 cm above the soil surface. Although the irrigation water used for the experiment represents an extreme case of saline water, the resulting "water stress" expressed as water potential might occur after several irrigation seasons using less saline water.

To allow for free drainage the bottom of each lysimeter had several holes 0.95 cm in diameter. The excess water, when it occurred, was intercepted by a plastic sheet catchment placed under each lysimeter, and collected in a bottle. Each lysimeter was initially flooded with tap water of low salinity and allowed to drain. The irrigation treatments began after the drainage ceased.

At the end of the experiment, two days after the last irrigation, a core sampler was used to take, in a grid manner, 42 samples from each lysimeter. Figure 1 shows the sampling arrangement. These samples were analyzed for water content, bulk density, and saturation extract conductivity. The conductivities of the saturation extracts were converted to osmotic potentials using the graphic relationship for $CaCl_2$ presented by the U.S. Salinity Laboratory Staff (1959). The osmotic potentials of the saturation extracts were corrected for the actual water contents of the soil profile at the time of sampling.

To determine the matric potential for all of the sample points in each lysimeter, a soil water

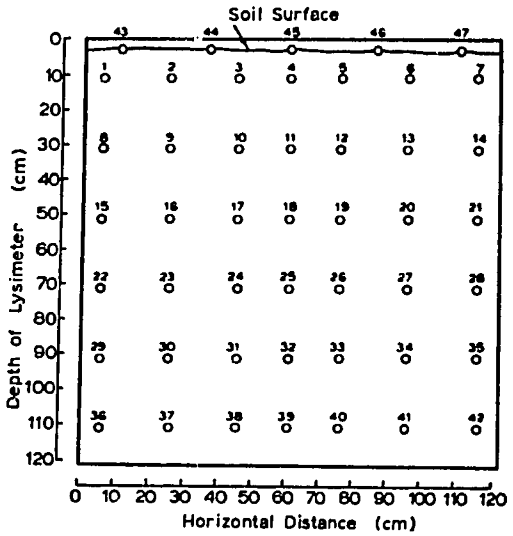

FIG. 1. Lysimeter soil sampling arrangements. Samples for saturation extracts were taken at positions 1–47, soil moisture samples were taken at positions 1–42, and bulk density samples were obtained from positions 9, 11, 13, 23, 24, 27, 37, 39, and 41.

characteristic curve was constructed for the soil using the data obtained with a pressure plate apparatus.

Results and discussion

At the time of sampling it was noticed that the root systems were essentially uniformly distributed in the entire volume of soil, except for the 10 to 20 cm of the bottom of each lysimeter on treatments A, B, and D which contained a saturated layer. The roots within this layer were scarce. The root pattern of Treatment C occupied the entire volume and the roots were more fibrous than the roots of the other treatments, due, perhaps, to the underirrigation.

For every treatment the two replications yielded essentially the same salt distribution patterns. A typical soil water potential profile for each treatment is discussed below.

For Treatment A, the irrigation was applied daily to satisfy the evapotranspiration demands of the previous day. A total of 105 cm of water was applied in 57 irrigations incorporating an equivalent of 0.14 percent of the soil weight in salt.

Figure 2 shows the final soil water potential profile for Treatment A. Each line represents equal water potential two days after the last irrigation. The irrigation water had an osmotic potential of −1.6 bars, the highest possible water potential attainable in the soil profile.

Values lower than −1.6 bars would indicate a buildup of salts, causing a decrease in the osmotic potential, and/or a drying of the soil causing a decrease in the matric potential. For the trickle irrigation management system used, however, the dry weight water contents were rarely less than 5 percent for any treatment. The soil water characteristic curve for the sandy loam soil indicated that this water content corresponded to a matric potential of −0.33 bar. Therefore, the magnitude of the water potential is almost entirely due to the osmotic potential and only minimally influenced by the matric potential.

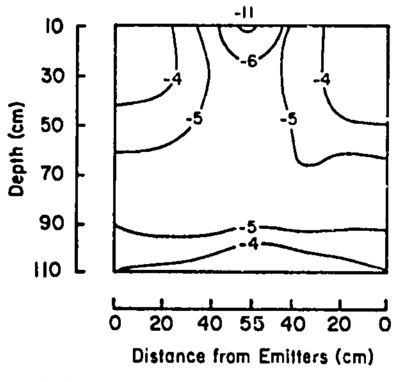

FIG. 2. Soil water potential patterns at the end of the experiment, in bars, for Treatment A, which was trickle-irrigated daily with an amount of water equal to evapotranspiration.

In the upper portion of the soil profile for Treatment A, represented in Figure 2, the soil water potential decreases as the horizontal and vertical distances from the emitters increase. There is a middle zone of uniform low potential, −6.0 to −5.0 bars, and then a lower zone where the potential increases from −5.0 to −4.0 bars. A small region of low potential, −11.0 to −6.0 bars, occurs midway between the emitters 10 cm below the soil surface. The area of least stress for the tomato plants, −5.0 to −3.0 bars, is the bulblike zones in the upper corners near the emitters.

Figure 2 also illustrates that for the irrigation management Treatment A, where the daily irrigation equals the evapotranspiration, there is no appreciable zone without an accumulation of salts. A zone of minimum salt accumulation would have a soil water potential of −1.6 bars, i.e., that of the irrigation water, if the relative minimal effects of the matric potential were neglected.

For Treatment B, the irrigation and evapotranspiration amounts were equal as in Treatment A, but under this treatment, water was applied every other day at a rate of 2.0 liters per hour for a time long enough to replace the water used the previous two days. Treatment B lasted two weeks longer than Treatment A, and a total of 121 cm of water was applied, incorporating in the profile an equivalent of 0.16 percent of soil weight in salt.

Figure 3 shows the final soil water potential profile for Treatment B. As in the profile of Treatment A, the soil water potential in the upper zone of the soil profile decreases with the horizontal and vertical distances from the emitters and the plants ranging from −7.0 to −3.0 bars. A small region of low potential, −12.0 to −8.0 bars, occurs midway between the emitters near the soil surface.

The final soil water potentials for Treatment

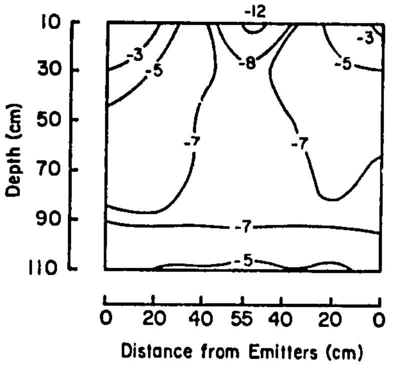

FIG. 3. Soil water potential patterns at the end of the experiment, in bars, for Treatment B, which was trickle irrigated every other day with an amount of water equal to the evapotranspiration.

B differ slightly from those found in Treatment A due to the additional salts that were incorporated in the profile as a result of continuing the irrigation scheme for two more weeks. Apparently, equivalent soil water potential patterns are to be expected when saline water is applied daily or every other day to restore in the root zone only the water evapotranspired between irrigations.

Treatment C specifies an alternate-day irrigation of a volume approximately equal to 87 percent of the water evapotranspired the previous day. A total of 95 cm of water was applied by irrigation while 109 cm were evapotranspired by the tomato plants. Under this treatment a portion of the water initially retained within the soil profile was gradually depleted. The total irrigation in Treatment C was 13 cm below its evapotranspiration and 25 cm below that of Treatment B. This indicates that because of the stress imposed, the evapotranspiration declined in Treatment C, even though additional water was extracted from that stored in the soil profile before planting the tomato plants in the lysimeter.

Figure 4 shows the final soil water potential profile for Treatment C two days after the last irrigation. Low soil water potentials are uniformly distributed within most of the profile. An equivalent of 0.13 percent of soil weight in salt was added to the profile with the irrigation water which represents 21 percent less than the total salt retained in the soil profile under treatment B. In spite of this, lower water potentials resulted under Treatment C. Water in the soil profile ranged between 5 and 6.5 percent, on a dry weight basis, which corresponded to a matric potential of approximately −0.3 bar. Although the matric potential varied very little at water contents above 5 percent, the water contents for Treatment C were generally one-half of those found in the profile of Treatment B at the time of sampling, that is, two days after the last irrigation. Therefore, the corresponding final osmotic potentials of Treatment C were nearly twice as low as those of Treatment B.

The resulting soil water potential patterns in Treatment C illustrate the importance of maintaining a high water content in the soil whenever highly saline water is used with trickle irrigation. Although a reduction in water content of the soil might not appreciably lower the matric potential, the effect on the osmotic potential would be greater, resulting in a lower soil water potential that might severely affect the plant growth. Immediately after irrigation the soil profile under Treatment C would have a zone of higher soil water potential than that indicated in Figure 4, especially in the neighborhood of the emitters. However, for much of the root zone during most of the irrigation season the soil water potential might be low, especially after several months of irrigating with saline water.

For treatment D alternate-day irrigations in excess of the evapotranspiration were applied. The total water evapotranspired was 145 cm while the total water drained as a result of overirrigation was 31 cm.

The effect of Treatment D on the soil water

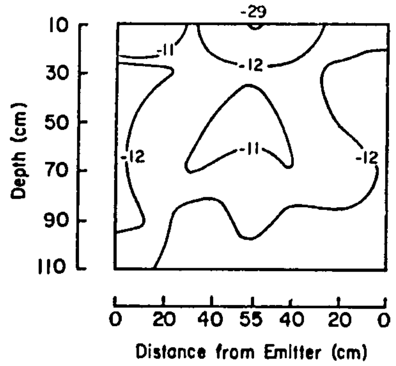

FIG. 4. Soil water potential patterns at the end of the experiment, in bars, for Treatment C, which was trickle-irrigated every other day with an amount of water below evapotranspiration.

potential patterns is presented in Figure 5. An equivalent of 0.27 percent of the soil weight in salt was applied with the irrigation water, and 0.15 was retained in the soil profile. The isowater potential lines are more elongated than those in the other treatments, reflecting the effect of leaching that took place during the experiment. Although nearly 50 percent more salts were applied with the irrigation water in Treatment D than in Treatment B, the soil water potentials of the soil profile under Treatment D are considerably higher at corresponding locations in the profile. In addition there is an appreciable zone near each emitter where the soil water potential is equal to or greater than −2.0 bars, which is approximately the osmotic potential of the irrigation water. The occurrence of this zone of no salt accumulation was not found in any of the other water management treatments, not even in Treatment A which retained, in the soil profile, less salt than Treatment D, but results in lower water potentials.

Table 1 contains the average surface saturation extract conductivities, EC_e, at the 2.0-cm depth for all experimental treatments, expressed in mmhos/cm. The samples were taken one day after the last irrigation.

High EC_e values were found in the soil surfaces for all the treatments. The EC_e increased at the soil surface with the horizontal surface advance of the wetting front and became extremely high at the mid-region between emitters where the two wetting fronts contributed to the accumulation of salts.

Under Treatment A the water was applied at a very slow rate. Treatment D received 1.2 times the water evapotranspired the previous day. Therefore, Treatments A and D required longer irrigations than Treatment B and C, the under-irrigated treatment. Longer duration of irrigation resulted in farther horizontal displacement of the wetting front. Treatments B and C had the lowest EC_e at the 55 cm surface distance from the tricklers. Treatment B, because of a high water application rate, had irrigations of shorter duration which became even shorter as the growing season progressed, when the daily rate of evapotranspiration decreased. At higher rates of evapotranspiration, Treatment B had longer irrigations which might have resulted in some salt displacement towards the point between emitters. Later in the season shorter irrigations were needed which did not contribute with salts to this midpoint. Treatment C had the least surface salt concentration at the midpoint. It also had the shorter irrigations. Table 1 also indicates that, in spite of low EC_e values at the midpoint, treatments B and C reached the highest EC_e values at the 30-cm distance from the emitters.

Concentration of salt at the soil surface, as a result of trickle irrigation with saline water, may hinder seed germination, stunt growth, and even kill young plants. Salt concentration at the soil

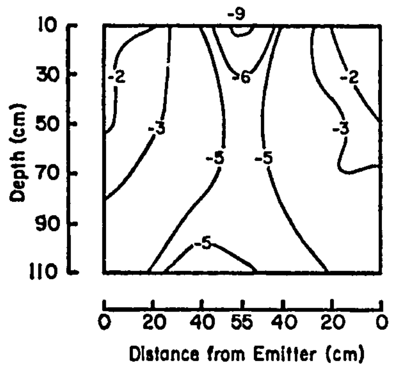

FIG. 5. Soil water potential patterns at the end of the experiment, in bars, for Treatment D, which was trickle-irrigated every other day with an amount of water above evapotranspiration.

TABLE 1

Average saturation extract conductivities, in mmhos/cm, for the top 2 cm depth of soil at various distances from the emitters

Treatment	Distance from emitters (*cm*)				
	5	30	55	30	5
A	9.8	36.0	78.6	40.5	7.6
B	9.5	74.0	24.0	71.7	10.8
C	8.0	64.5	2.2	63.0	17.8
D	14.3	62.5	104.5	57.0	15.8

TABLE 2

Yields and weights of green tomato plants

Treatment	Plant weight (*g*)	Total yield (*g*)
A	1950	3400
B	2400	4800
C	2350	4650
D	3000	5150

surface should be considered in the management practices especially when planting a seasonal crop in a previously trickle-irrigated field and where downward salt displacement might occur as a result of sporadic precipitation.

Although the experiment was not to study salt effects on productivity, Table 2 was prepared to show the green plant weights for all treatments, and the total weight of tomatoes harvested. Since the main objective of the investigation was to study the changes in soil water potential as a result of irrigation with a highly salt-concentrated water, no control treatment, irrigated with nonsaline water, was included. Nevertheless, Table 2 shows Treatment D as having higher tomato yields and plant weights than the other treatments. This coincides with the lowest soil water potentials at the termination of the experiment.

SUMMARY AND CONCLUSIONS

The soil water potential patterns in soil profiles, subjected to four different trickle irrigation management treatments with highly saline water, were investigated.

The soil water potential reflected both the changes in matric and solute potentials that took place during the experiment. Changes in water content resulted in small variations in matric potential but greatly increased the salt concentration in the soil solution yielding high solute potentials.

The soil water potential patterns indicated that most of the water used by the plants was extracted from the vicinity of the emitters where a relatively high water potential was available. The salts accumulated at the periphery of the active portion of the root zone and the water potentials decreased as the distances from the emitters increased.

High potentials were found in the profiles irrigated with 20 percent more water than was evapotranspired. A distinct zone of nonsalt accumulation with potentials near the solute potential of the irrigation water was evident in the vicinity of the emitters.

The evapotranspiration declined in the profiles which received less water than was evapotranspired. Low water potentials were uniformly distributed throughout most of these soil profiles.

High surface salt concentrations were found at the 2.0-cm depth for all experimental treatments. Surface salt accumulation at the midpoint between the emitters was greatest for the treatments with longer duration of irrigations.

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