The Distribution of Roots, Water and Minerals as a Result of Trickle Irrigation

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Abstract. The effect of trickle irrigation on the distribution of roots, water and minerals was studied in a 3-dimensional soil profile. Root exploration was shallow, mainly to a depth of 10 cm and concd close to the nozzles. The content of soluble salts, including those added as fertilizer, was high in the upper 3 cm, especially midway between adjacent nozzles. When P and N were added with the irrigation water, P tended to accumulate beside and below the nozzles, while the N was leached below the nozzles and also accumulated in the area between them.

Trickle irrigation, the application of small amounts of water slowly discharged through perforations in distribution lines, is becoming wide-spread in Israel. The number of crops irrigated by this method is growing rapidly. The advantages of the system include the constant provision of available water to the plant at a low rate, the maintenance of a low soil moisture suction, and the possibility of using marginal land and saline water which could not normally be exploited. Because of its many agrotechnical advantages, the method is presently being used with fertile soil and good water quality for the production of intensively cultivated crops.

A trickle irrigation system can be used to supply the plant with all the required nutrient elements by adding them regularly and in controlled amounts with the irrigation water. The uniformity of distribution of these nutrients within the root zone depends upon the proper distribution of the irrigation water, on the solubility of the minerals, and on their ability to be transported by the water in the soil.

There is danger of salination and the concn of salts in the root zone of a trickle irrigated crop. Water movement in trickle irrigation is 3-dimensional (compared to one-dimensional in sprinkling), and the possibility of salt accumulation exists, especially under arid conditions and in plastic greenhouses where there is no natural leaching due to rainfall.

This paper reports a study concerned with the effect of trickle irrigation on the distribution of roots, water, nutrients, and salinity in a 3-dimensional profile.

Materials and Methods

The study was conducted with carnations, cv. Red Sim, growing in a plastic greenhouse. The beds were 90 cm wide, with 6 rows of carnations on each bed. The plants were 10 cm apart within the row. Properties of the soil and the irrigation water are presented in Table 1.

The crop was trickle-irrigated from planting until the end of the cutting season, using nozzles having a discharge of 2 liters/hr. Each bed had 2 irrigation lines, 45 cm apart, located between the first and second rows, and between the fourth and fifth rows. The individual nozzles were 50 cm apart within the row. The irrigation was automatically controlled by electro-tensiometers. The amount of water applied varied between 2.2 mm/day in January to 5.0 mm/day in May.

Fertilizer was supplied at each irrigation through the trickle system. A complete mixture was used, containing 20:20:20 NPK, and the amount applied was equivalent to 20 kg/ha, or 400 g N. A high yield was obtained, with 55,716 flowers being cut from an area of 0.05 ha.

After preliminary determinations of the maximum root depth, a section of a well-developed bed in blossom was selected for detailed soil studies. All the plants were cut from an area including the full width of the bed and the distance between 2 adjacent nozzles. A rectangle was thus obtained, 50 x 90 cm in size, containing 30 plant stems. A soil block was isolated by excavating on the ends of this rectangle to a depth of 40 cm.

The block was divided into 5 sections in the length of the bed, 6 sections in the width (designated a to e) and 5 layers in depth (designated a to e). The first layer, a, was 3 cm deep, the second, b, was 7 cm, and the others, c, d, and e, 10 cm each. The block was thus divided into a total of 150 units, each one being 15 cm long, 10 cm wide and between 3 to 10 cm deep (Fig. 1).

Table 1. Properties of the experimental soil and the irrigation water.

<table>
<thead>
<tr>
<th>Soil</th>
<th>0-30 cm</th>
<th>30-60 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texture</td>
<td>loamy sand</td>
<td>loamy sand</td>
</tr>
<tr>
<td>Bulk density, g/cm²</td>
<td>1.55</td>
<td>1.57</td>
</tr>
<tr>
<td>Field capacity (dry wt. basis), %</td>
<td>8.2</td>
<td>7.8</td>
</tr>
<tr>
<td>pH</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Electrical conductivity, mmhos/cm</td>
<td>0.1</td>
<td>0.08</td>
</tr>
<tr>
<td>Water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical conductivity, mmhos/cm</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Total soluble salts, mg/l</td>
<td>353</td>
<td></td>
</tr>
<tr>
<td>Calcium content, mg/l</td>
<td>82.1</td>
<td></td>
</tr>
<tr>
<td>Sodium-adsorption-ratio</td>
<td>1.03</td>
<td></td>
</tr>
<tr>
<td>Chloride content, mg/l</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>Sulphate content, mg/l</td>
<td>13.2</td>
<td></td>
</tr>
<tr>
<td>Nitrate content, mg/l</td>
<td>25.8</td>
<td></td>
</tr>
</tbody>
</table>

The following determinations were made in each of the soil units.

(a) Root wt. A certain amount of soil was removed from the unit for moisture and chemical determinations, and the remainder was washed through a sieve to separate the roots which were then dried at 80°C and weighed. (b) Soil moisture. The soil moisture content, on a dry wt. basis, was determined by drying at 105°C. (c) Nitrate and phosphate content, expressed in ppm. (d) Electrical conductivity, expressed in mmhos/cm, was determined using extracts of a 1:1 soil-water paste. (e) Chloride content, expressed in meq/l.

The chemical determinations were performed using standard methods (1).

Results

Root wt. The outstanding observation concerning root development was that 76% of the total root wt was located in the upper 10 cm of soil, with the major part being in the 3 to 10-cm layer (Fig. 2). In this layer, the amount of roots varied in

1Received for publication December 29, 1970. Contribution of the Department of Irrigation.

2Professor and Soil Scientists, respectively.
Fig. 1. Sketch of the soil block and its division into 150 units.

the width of the bed from section 1 to section 6. There were less roots at the extremes and more near the trickle nozzles (Fig. 3).

Fig. 2. Distribution of carnation roots in the various soil layers, expressed as a percentage of the total wt.

Soil moisture distribution. Within the width of the bed, from section 1 to 6, there was a reduction in moisture content in the upper-most layer, a, and in the lowest layer, e (Fig. 4). In both of these layers, the most marked decrease occurred in the region between the nozzles. At other depths in the width and length of the bed, the moisture content was fairly uniform. The uniform moisture content in layers b, c, and d is probably due to the high moisture content (above field capacity) in these layers, and also to the high hydraulic conductivity of the soil. The high concn of water, especially below the nozzles, suggests that there is a certain amount of drainage below the root zone at these locations.

Nitrate content. In the upper soil layers, the NO$_3$ content tended to be lower below the nozzles and higher at the edges of the bed and in the region between the nozzles. In the deepest layer, e, the opposite condition was recorded, as shown in Fig. 5. The relatively high N content in the lowest soil layer below the nozzle is related to the water movement in the soil. The natural drainage of the sandy loam soil enables the water to leach the N below the root zone. Because of the frequency of irrigation and the supply of fertilizer with each water application, it is difficult to differentiate between the 2 processes: N application and N leaching. Thus, (Fig. 5) illustrates the equilibrium status of the soil.

Fig. 3. Root distribution in the width of the bed, at the various soil depths.

Fig. 4. Soil moisture content at different depths in the profile.
Phosphate content. The phosphate distribution was unlike that of the NO$_3$ (Fig. 6). At all the depths there was a lower concn in section 3, and at most of the depths there was a higher concn at sections 2 and 5.

Electrical conductivity. The values obtained from electrical conductivity determinations are presented in Fig. 7. The conductivity was found to be highest in the top 3 cm of soil (depth a) at all locations across the width of the bed. There was a general increase in conductivity in section 3, midway between the nozzles. In the 2 upper layers, there was an increase in section 6 as well, which was also somewhat distant from trickle irrigation line (Fig. 7).

Chloride content. The results of the chloride determinations were similar to those obtained for electrical conductivity: a high concn in the upper soil layers, and especially at the midpoint between nozzles or at points distant from them (Fig. 8).

Discussion and Conclusions

The basic assumption that the spread of minerals in the soil depends on their solubility, on the moisture distribution, and on the direction of water movement, was verified by the results obtained from the present study of a 3-dimensional profile.

Figure 9 illustrates the accumulation of salt and the distribution of moisture, nitrate, phosphate, and chloride in the soil according to the various determinations. The distribution of these parameters can be affected by crop, soil and water factors, irrigation method (including spacing and discharge rate of the nozzles) and type and form of fertilizer.

Dense root growth is found in the vicinity of the nozzle, and the growth becomes sparse as the distance from the nozzle increases. Thus, if small plants are closely spaced in the bed or row, it is important that water and nutrient materials be uniformly distributed. The trickle irrigation method encourages the development of a shallow root system, as observed in pepper and other crops (5), and this emphasizes the need for uniform distribution of water and nutrients.

The concn of soluble salts (including those added as fertilizer) is high near the soil surface, and especially at the midpoint between adjacent nozzles. This concn will gradually increase if the salt content of the soil or water is high, and if the wetting fronts between the 2 nozzles meet at a greater depth. It is possible to increase, somewhat, the distance that the wetting front spreads from the nozzle by increasing the discharge or the amount of water applied (4). This will result in a higher point of contact of the wetting fronts (Fig. 9), and the movement of...
Phosphate accumulation

Fig. 9. Distribution of moisture and minerals in the soil profile, between 2 trickle nozzles.

Water downwards will leach part of the surplus salts. If the soil's infiltration capacity is high and the lateral movement of water is low (as in sandy soil), it is essential to use a closer nozzle spacing.

Since N and P are not equally soluble, they cannot be uniformly distributed in the soil by the same irrigation method. The movement of P with water is limited and it becomes coned near the nozzle, while N moves readily with the water and its concn near the nozzle becomes relatively low. Furthermore, root density in the vicinity of the nozzle may reduce the N concn. Increasing the water application in an attempt to better distribute the P will only result in a reduced N content in the root zone. It seems, therefore, that those elements of low solubility or those which are fixed and become insoluble upon contact with the soil, should not be applied through the trickle irrigation system.

Literature Cited