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Full Length Research Paper

The impact of irrigation water quality on water uptake by orange trees

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A greenhouse lysimeter study was carried out in Tottori (Japan) during August 2000 to explore the impacts of saline irrigation on water uptake by orange trees. Two lysimeters filled with sandy soil were used. Each lysimeter was planted with a tree. During the first half of August, both lysimeters (L1 and L2) were irrigated with non-saline water. In the second half of the month, L1 was irrigated with non-saline water (1.0 dS/m) and L2 with saline water (8.6 dS/m). At each irrigation event, 60 and 32 mm water was applied in the first and second half of August, respectively, when average water content of the soil profile was depleted to 70% of field capacity. Osmotic potential in L2 became more negative after application of the saline water. Evapotranspiration from L1 was consistently higher than that from L2. Average transpiration rate (T) reached 5.5 mm/day under non-saline irrigation, while T was only 3.8 mm/day under saline treatment. Up to 99.5% of roots were in the top 60 cm of soil and 73% of the total water uptake was extracted from the same layer. Maximum water withdrawal by the tree was observed at layer of 30 - 60 cm in accordance with root-weight distribution.

Key words: Saline water, orange trees, water uptake.

INTRODUCTION

Arid and semi-arid regions comprise almost 40% of the world's land surface. Water scarcity is the single most significant contributor for limiting crop production in such lands (Aydin, 1995; UNEP, 1999; 2002). In addition, water scarcity prevents the use of freshwater for irrigation. Therefore, saline water irrigation is often practiced in several regions of the world (Rhoades et al., 1992; Amaya and Yano, 1994; Shalhevet, 1994; Khroda, 1996; Yang et al., 2002). As water resources become scarce, the determination of crop water requirements is an important component in irrigated agriculture for water saving, controlling water table level, drainage volume, and the final yield (Ragab, 2002; Yang et al., 2003). To obtain a greater understanding of the effects of crop management on water use, it is necessary to predict the different components of soil-water balance (Aydin, 1994).

For example, transpiration through crops is regarded as beneficial, but evaporation from bare soils in irrigated fields with a partial canopy cover is considered detrimental (Droogers and Bastiaanssen, 2002; Aydin et al., 2008).

Citrus is one of the most important irrigated crops. In literature, there are many investigations dealing with water requirement of citrus trees irrigated with good quality water (Hoffman et al., 1982; Ginestar and Castel, 1996; Syvertsen and Smith, 1996; Fares and Alva, 1999, 2000a, 2000b; Gonzalez-Altozano and Castel, 1999, 2000; Grismer, 2000). On the other hand, despite many studies conducted for determining the effects of saline water on fruit set, size, quality and yield (Cole and McLeod, 1985; Francois and Clark, 1980; Howie and Lioyd, 1989; Levy et al., 1999), there is insufficient quantitative knowledge about the influence of saline irrigation on water use; more importantly, water uptake pattern of citrus roots is not generally known. This information may be essential for soil-water management (FAO, 1985).

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The objectives of this study were to compare the energy state of water in the soils under saline and non-saline irrigation and to examine the relations between water uptake pattern and root distribution of orange trees.

MATERIALS AND METHODS

Eight-year-old Murcott orange trees (*Citrus sinensis* (L.) Murcott) grown in greenhouse lysimeters were subjected to investigate the effects of irrigation water quality on water uptake. The study was carried out at Arid Land Research Center (ALRC), Tottori University, Japan (35° 32' N and 134° 13' E).

Although citrus trees are known as sensitive to salt, 'Maukoto' trees tested in this experiment are salt-tolerant. Two weighing lysimeters filled with sandy soil (silicious sand and Typic Udipsamment) were used. Each lysimeter planted with a tree was surrounded by eight trees on the same sand in the greenhouse. The lysimeters with 1.5 m diameter and 1.6 m depth had a resolution of 50 g, corresponding to 0.028 mm of water. They were connected to a terminal computer. Samples were recorded every 15 s and averaged every 30 min. The lysimeters had a drainage system in which reservoir and drainage was monitored during the experimental period. Average field capacity (FC) and permanent wilting point of the sand in lysimeters were respectively 0.074 cm^3/cm^3 and 0.022 cm^3/cm^3, which correspond to –0.006 and –1.5 MPa, respectively in matric potential. On average, soil dry bulk density was 1.52 g/cm^3 (Yang et al., 2002, 2003).

Different treatments were applied to two respective lysimeters and their surrounding areas. The experiment was conducted during August, 2000. The experimental duration was divided into two periods with modified treatments. During the first half of August, both lysimeters (L1 and L2) were irrigated with non-saline water when average soil water content in 0 - 120 cm of soil depth was depleted to 70% of FC in order to obtain the same conditions in the lysimeters before salinity treatments. At each irrigation event 60 mm of water was applied. In the second half of August, both lysimeters were irrigated with 32 mm of water when soil water content was at 70% FC. During the second period, however, L1 was irrigated with non-saline water and L2 with saline water. The non-saline irrigation water was adjusted to 1.0 dS/m of electrical conductivity (EC_i) by adding chemical fertilizer (ingredient: N: 20%, P: 4%, K: 30% etc.). The saline irrigation water was adjusted to 8.6 dS/m of EC_i by adding sodium chloride (Yang et al., 2002).

Daily actual evapotranspiration (ET) was determined from changes in lysimeter weight and converted to the unit of mm d^{-1} based on the lysimeter surface area. Daily evaporation (E) from bare soil was measured by microlysimeter method (Boast and Robertson, 1982). The microlysimeters used in this study with three replications have been described by Yang et al. (2002, 2003). Daily transpiration (T) was calculated from the difference between evapotranspiration and evaporation (ET - E).

Soil water content was monitored with two-rod TDR sensors. The sensors were installed at 7.5, 22.5, 45, 75 and 105 cm depths in the soil, and at 35 cm lateral distance from the trunk of citrus trees in the lysimeters. Water content was calculated for 15 cm increments between 0 - 30 cm depth, and thereafter for 30 cm increments to 120 cm depth. The soil bulk electrical conductivity was measured using electrode-salinity sensors (Rhoades et al., 1976) installed at depths of 7.5, 22.5, 45 and 75 cm in the lysimeters (Yang et al., 2002, 2003). Electrical conductivity of soil-water (EC_S) was determined as the function of bulk electrical conductivity and volumetric water content by use of an experimentally obtained equation.

At the end of experiment, root samples were taken from 0 - 15, 15 - 30, 30 - 60 and 60 - 90 cm soil layers along with a distance of 35 cm from the truck in L1. The roots were washed free of soil and dried in an aerated oven at 70°C. Then, root-weight distribution was calculated for each soil layer.

RESULTS

The changes in soil-water storage (S) of the lysimeters are compared in Figure 1 along with irrigation events. Sharp increases and decreases in the storage were observed. A comparison of osmotic potential and relevant electrical conductivity of soil-water in lysimeters irrigated with non-saline and saline water is given in Figure 2. Evapotranspiration (ET) from lysimeter-grown orange trees along with evaporation (E) and drainage rates is shown in Figure 3. Evapotranspiration from L1 was consistently higher than that from L2 after the application of the saline water. The potential and content patterns of soil-water in lysimeters before and after saline water irrigation are depicted in Figure 4. As shown in Figure 5, no clear influence of water quality was observed on E from soil. Relation of final root distribution and average soil-water depletion in the lysimeter irrigated with non-saline water is demonstrated in Figure 6. Water uptake by roots from individual soil layers was in accordance with root-weight distribution.

DISCUSSION

The sharp increases and decreases in the storage (Figure 1) during irrigation events demonstrated the low water-holding capacity and high hydraulic conductivity of the soil. S values were similar in both lysimeters during the first half of the experiment because of the same treatments. However, S value of L2 was higher than that of L1 during the period of saline irrigation. This difference gradually increased along with the saline water application. The saline condition in the root zone might decrease water uptake because of higher negative values of osmotic potential and therefore much more water could remain in L2. At the end of experiment, S value in L2 was 31% higher than in L1. As mentioned above, the osmotic potential became more negative after application of the saline water into L2. This can be attributed to increased soil salinity (Figure 2).

Daily evapotranspiration was similar for both lysimeters during first half of the experiment (Figure 3). This is not surprising because the lysimeters were similarly irrigated with non-saline water. In the second half of August, ET from the lysimeter irrigated with non-saline water (L1) was consistently higher than that from lysimeter irrigated with saline water (L2). The average relative ET for L2 with respect to L1 was 0.71 as reported by Yang et al. (2002). Drainage rate (D) variations were almost similar in both lysimeters during non-saline irrigation schedule. Then, saline water irrigation increased the drainage volume when compared with the non-saline water, due to lower ET which was consequently higher than the antecedent

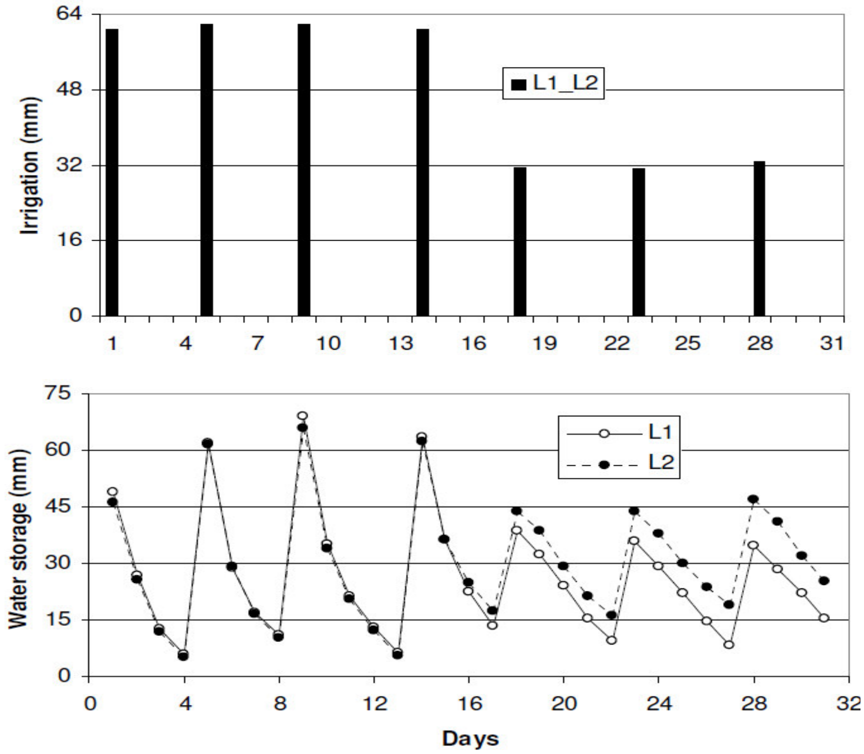

Figure 1. Comparison of changes in soil-water storage of the lysimeters (L1: Irrigated with non-saline water during the experiment; L2: Treatment was the same with that of L1 during the first half of August and then irrigated with saline water from the mid of experiment).

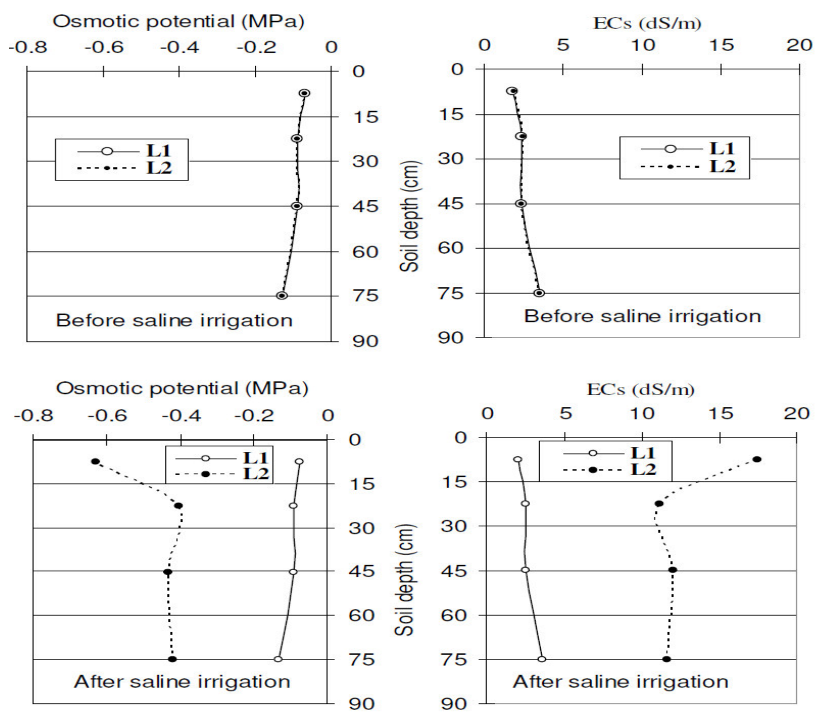

Figure 2. Comparison of osmotic potential and relevant electrical conductivity of soil-water (ECs) in lysimeters irrigated with non-saline (L1) and saline (L2) water.

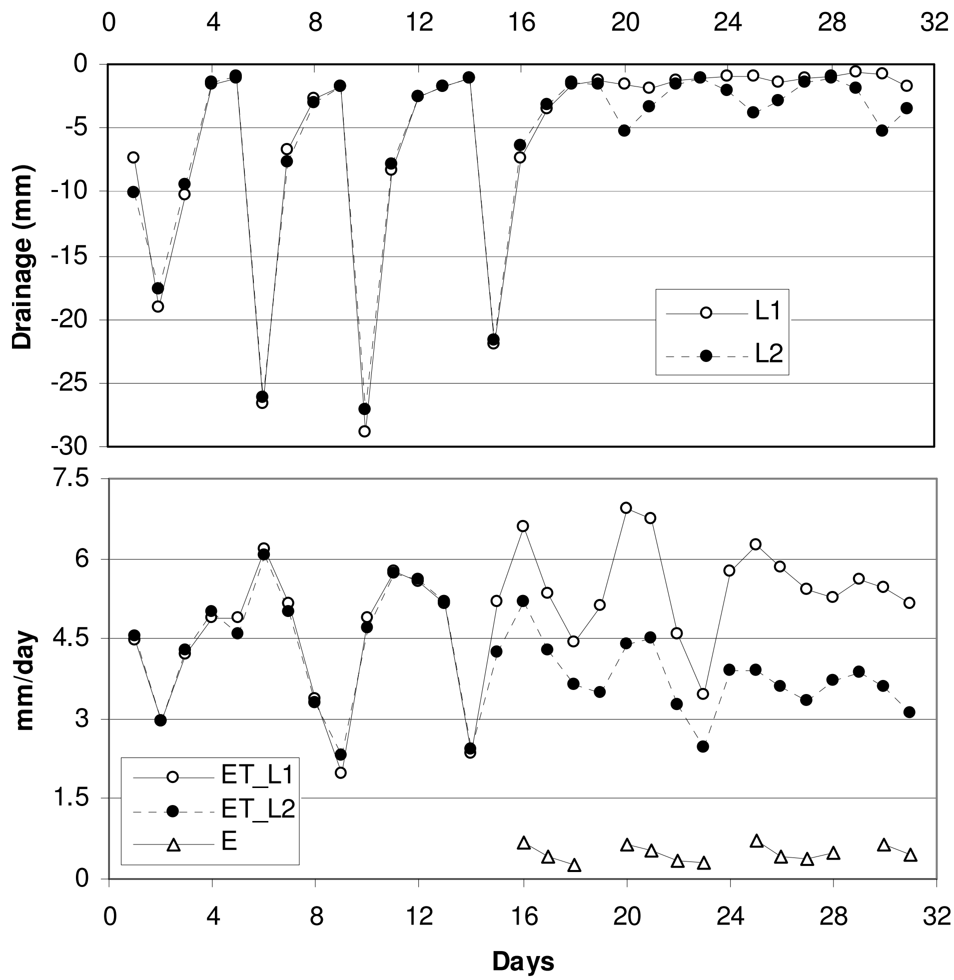

Figure 3. Evapotranspiration (ET) from lysimeter-grown orange trees along with evaporation (E) and drainage rates (L1: Irrigated with non-saline water during the experiment; L2: Treatment was the same with that of L1 during the first half of August and then irrigated with saline water from the middle of experiment. Data were derived from Yang et al. (2002).

water content. The cumulative drainage of L2 was 35% greater than that of L1.

Before saline water irrigation, the soil-water potential/content pattern is similar between two lysimeters due to the same irrigation schedule. After saline water irrigation, the patterns differed between two lysimeters. The differences in the total water potential (matric + osmotic) of the soils resembled the pattern of osmotic potential (Compare Figures 2 and 4). Influence of saline water on matric potential was inconspicuous during experimental period (Inoue and Nomura, 1983). The saline water irrigation resulted in lower soil-water potential and higher water content in the root zone compared with non-saline water irrigation. This result reflected a tangible impact of saline water irrigation on the magnitude of the soil water uptake by orange roots. No clear influence of water quality was observed on E from soil (Figure 5). This result is in agreement with findings of Dasberg et al. (1991) and Yang et al. (2002), who reported that evaporation from soil was not affected by soil salinity at small quantum of salts. Therefore, the difference observed in ET is a reflection of differences in transpiration magnitudes. Average transpiration (T) rate reached 5.5 mm/day under non-saline irrigation, while T was only 3.8 mm/day under saline treatment. Dasberg et al. (1991) also emphasized that with increase in soil salinity, water extraction by orange trees decreased. For the evaluation of water withdrawal by roots from individual soil layers, daily water content changes in soil layers were determined by using semi-automatic time domain reflectometer (TDR) equipment between irrigation cycles. Data lower than field capacities were used for this purpose to eliminate possible problems of water losses by seepage. In practice, a small amount of water can drain from the soil zone when the water content is slightly below field capacity (Eilers et al., 2007; Aydin, 2008), and this possible recharge is considered to be the main reason for water depletion in 90 - 120 cm layer (Figure 6).

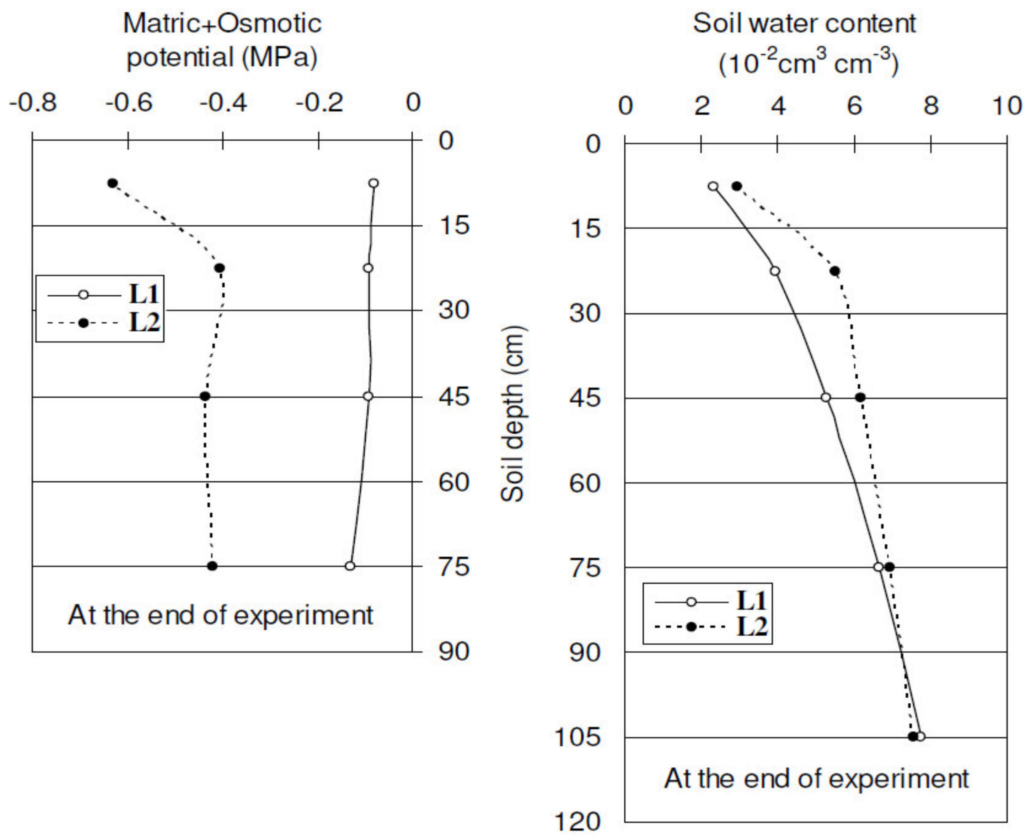

Figure 4. Comparison of total potential and content of soil-water in lysimeters irrigated with non-saline (L1) and saline (L2) water.

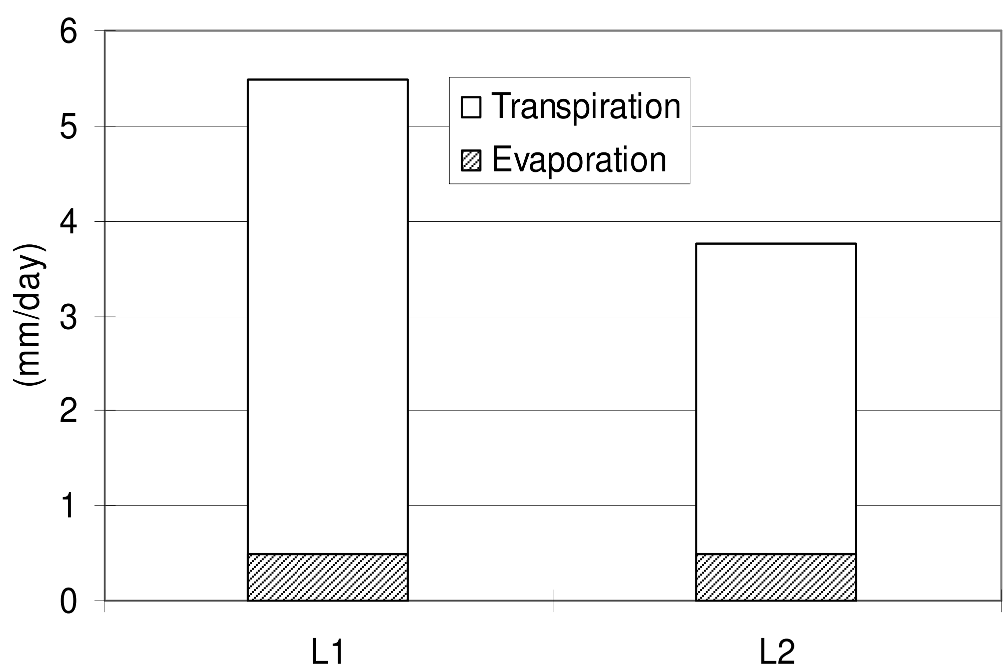

Figure 5. Average rates of evaporation from soil and transpiration from the orange trees grown in greenhouse lysimeters under irrigation with non-saline (L1) and saline (L2) water during the second half of August.

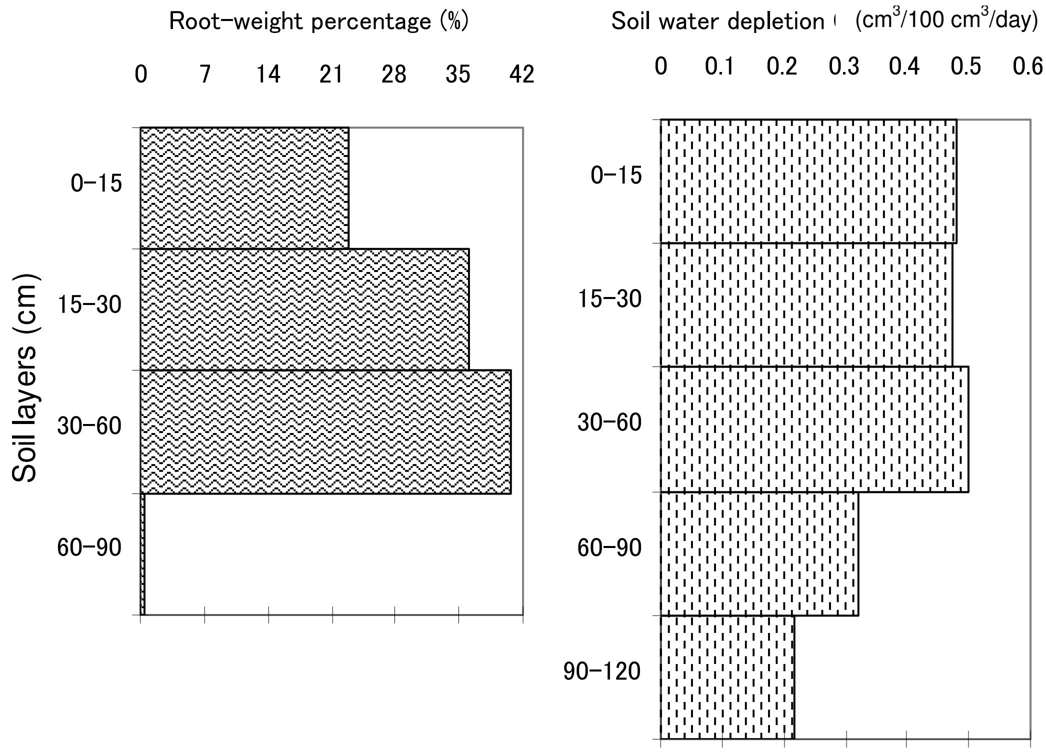

Figure 6. Relation of final root distribution and average soil-water depletion in the lysimeter irrigated with non-saline water.

It was assumed that capillary fluxes between layers of sandy soils were very low and could be neglected. This assumption may lead to minor errors. Similarly, Aydin (1994) reported that the capillary flux was very small when compared with root water uptake even in clay soils. A good agreement between root weight distribution and water uptake was found throughout the profile except for the top layer where the water depletion included the moisture loss by evaporation from this layer. These results may be compared with findings of Aydin (1994), working with cotton plants. Up to 99.5% of roots were found in the top 60 cm of soil profile. The water extracted from the same depth was determined as 73% of the total water uptake. Maximum water uptake by the tree was observed at layer of 30 - 60 cm in accordance with root-weight distribution. However, the growth conditions, variety and age of trees can affect the water extraction pattern (Yang et al., 2002).

Conclusions

The saline water irrigation resulted in lower soil-water potential and higher water content in the root zone compared with non-saline water irrigation. The differences in the total water potential (matric and osmotic) of the soils resembled the pattern of osmotic potential. Effect of saline water on matric potential was inconspicuous. There was no clear influence of water quality on evaporation from soil. However, irrigation with saline water tended to decrease transpiration. These results might reflect the impact of osmotic potential on the magnitude of the water uptake by orange roots.

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