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ORIGINAL PAPER

# Effects of water table management on soil salinity and alfalfa yield in a semi-arid climate

**Hamideh Noory · Abdol-Majid Liaghat ·**
**Mohamad Reza Chaichi · Masoud Parsinejad**

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**Abstract** A lysimeter experiment was conducted to investigate the effect of water table management (WTM) on distribution of soil salinity and annual alfalfa (*Medicago scutellata*) yield. Subirrigations with three levels of water table namely, 0.5 (WT0.5), 0.7 (WT0.7), and 1.0 m (WT1.0) and a free drainage (FD) conventional irrigation treatment were selected for this study. All treatments were arranged in a complete randomized block design with three replicates. The results of this study indicated that the average soil electrical conductivity of the saturated extract (ECe) in the root zone gradually increased and exceeded the designated crop threshold value (4 dS/m) after the first forage harvest in subirrigated lysimeters. A higher salt accumulation was observed at the WT0.5 treatment. The average dry matter yield of annual alfalfa in WT0.5 and WT0.7 treatments was found to be 52 and 73% higher compared with the control treatment, respectively.

## Introduction

Water table management has shown to increase crop production and drainage water quality in humid regions (Workman et al. 1990; Kalita et al. 1992; Fisher et al. 1999; Jia et al. 2006). Conventional subsurface drainage has long been proved to have substantial impact on quality and quantity of various crop productions, whereas many recent studies have shown that many crops respond more favorably to the practice of controlled drainage and subirrigation systems, instead (Soppe et al. 2001; Fausey and Baker 2003; Ayars et al. 2003). In controlled drainage system, the drain outlet is raised to a specified level in order to retain a portion of percolating water in the soil profile to supplement crop water requirements. In subirrigation system, however, water is introduced through subsurface drainage pipes to maintain the water table just below the root zone to fulfill crop water requirements (Fausey and Baker 2003). Some of the advantages attributed to WTM are: reduction in drainage water and losses of chemicals, reduction in environmental pollution, and provision of a better soil-water environment for crop growth (Skaggs and Evans 1996; Mejia et al. 2000). Skaggs et al. (1999) compared the performance of controlled drainage, subirrigation and free drainage systems for management of drainage water in a 4-ha field study. Nitrate concentration of drainage water was reduced by 63% in the controlled drainage system and the total nitrate losses were reduced by 50% compared with the free drainage system. Tomato and corn yields in the subirrigation system were 44 and 64% more than those in the free drainage system, respectively. Ahonen (1991) reported a 10% increase in potato yield in the subirrigation as compared to the free drainage system. Mejia et al. (1998) also reported 75-84% reduction of nitrate losses and 42% increase in corn yield through water table management.

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H. Noory · A.-M. Liaghat · M. Parsinejad
Department of Irrigation and Reclamation Engineering,
University of Tehran, Tehran, Iran

M. R. Chaichi
Department of Agronomy,
University of Tehran, Tehran, Iran

H. Noory (✉)
Department of Irrigation and Reclamation Engineering,
Agriculture and Natural Resource Campus,
University of Tehran, Tehran, Iran
e-mail: hnoory@ut.ac.ir

A study performed on a Ravenna silt loam showed that the average yield of subirrigated soybeans over a 5-year period was 5.22 Mg, whereas the non-irrigated yield over the same period was limited to 3.44 Mg (Fausey and Cooper 1995). Controlled drainage and subirrigation can also improve conservation of water during drought (Skaggs and Gilliam 1981; Evans et al. 1995; Meija and Madramootoo 1998). Lothar et al. (2005) quantified the water use efficiency of several crops at shallow water table in temperate climate. They showed that water requirements strongly depend on the level of water control and the type of crops.

Freshwater supplies are becoming more limited in dry regions, while the demand for food is increasing globally (FAO 1995a). There are numerous problems in arid and semi-arid regions associated with the practice of surface irrigation using brackish water (FAO 2002). Sensitivity of young plants to saline water and the extent of salt buildup within the root zone during growing season are among the most serious limitations in this respect (Von Hoyningen Huene 1994; Patel et al. 1999). However, a number of studies have reported positive impacts of adopting controlled drainage and subirrigation in arid and semi-arid regions by reducing drainage discharge and saving irrigation water (Abbott et al. 2001; Khalil et al. 2004). Patel et al. (2001) investigated the effect of initial soil salinity and salinity level of brackish subirrigation water on tuber weight of potato under simulated arid condition. The average root zone salinities were found to be 3.2–3.7 dS/m in lysimeters subirrigated with 1 and 9 dS/m of water, respectively. There was no significant effect of either initial soil salinity or subirrigation water salinity on the total tuber weight. Therefore, more work is needed to investigate the effectiveness of WTM on soil salinity profile and crop yield.

Adoption of subirrigation system in semi-arid regions like Khoozestan province in the south and Moghan region in the northwest of Iran is feasible, due to the existence of a shallow water table. Discharge of massive amounts of brackish drainage water from the existing irrigated lands has imposed major environmental problems, which could significantly be tempered using WTM systems. The objective of this study was to investigate the effect of the subirrigation system on the salt profile in the root zone of annual alfalfa in the semi-arid climatic conditions of Karaj, Iran.

## Materials and methods

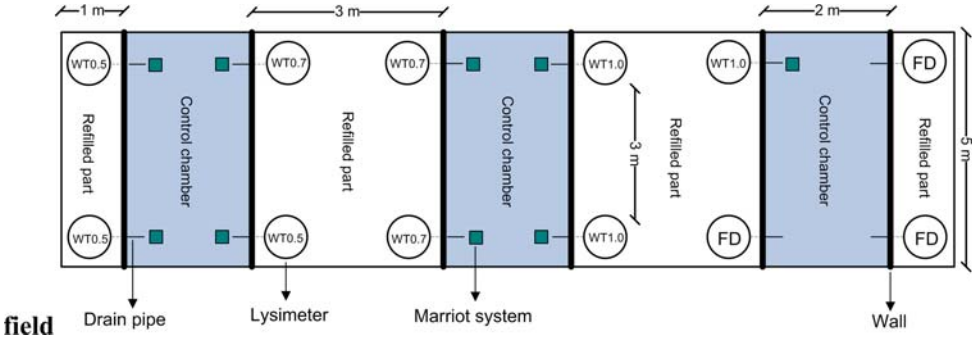
### Lysimeter construction

The study was carried out in 2005 and 2006 (March–July) in the research field at the Soil and Water Research Center of Tehran University (35°56′N, 50°58′E), in the city of Karaj, Iran. The study was conducted with 12 lysimeters installed in the middle of a 0.8-ha field (Fig. 1). The soil was excavated in order to place the lysimeters at a certain depth so that their top was on level with the ground surface. The excavated soil was then placed back into the lysimeters and the surrounding space, preserving the profile similar to the field soil. The 1.5-m height lysimeters were made up of 0.7-m diameter polyethylene pipes, with the bottom end sealed with a circular flat plate. A perforated pipe, 0.05 m in diameter, was installed just above the bottom of each lysimeter to allow the drainage of water through the lysimeter (Fig. 2). In the subirrigated lysimeters, the drain pipes were connected to a gauged riser pipe to maintain and control the water table to the specified depth. As the plants were consuming water from the water table, the level of water had to continuously be preserved at the specified depth. For this reason, a Marriot system was installed into the control chamber beside the lysimeters to automatically resupply the plant with water (Fig. 1). The depleted amount of water from the storage tank at a certain period of time could then be assumed as the net plant water use. The controlled water level in the lysimeters was also monitored by a piezometer installed in each one.

### Data collection

Measured physical and chemical properties of the soil profile are presented in Table 1. The soil is classified as Xeric Haplocambids, Entisols, with smectites as the main clay mineral. Volumetric water content at field capacity, and

**Fig. 1** Experimental field layout



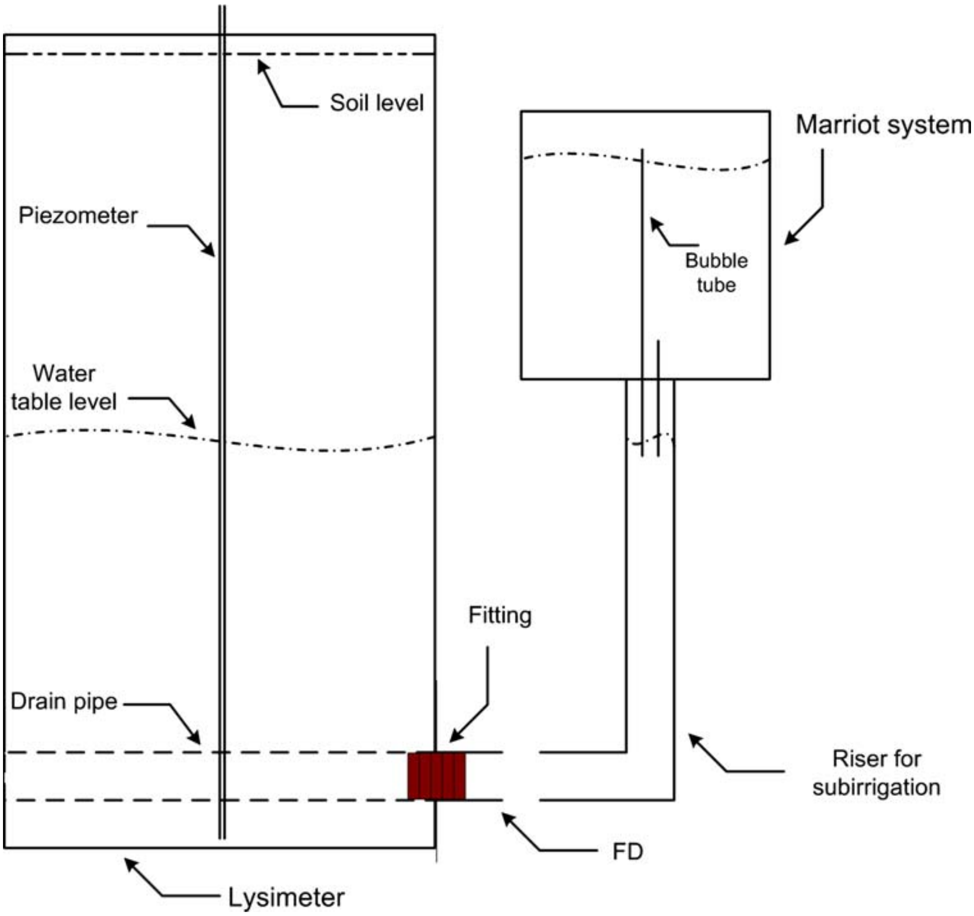


**Fig. 2** Schematic of a lysimeter

**Table 1** Physical and chemical properties of the soil

| Depth (m) | Particle size distribution (%) | | | | Texture | $K_s$ (m/s) | $I$ (m/s) | $\rho_b$ (kg/m$^3$) | pH | ECe (dS/m) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Coarse sand | Fine sand | Silt | Clay | | | | | | |
| 0–0.3 | 2.58 | 25.22 | 41.26 | 30.94 | Clay loam | $2.38 \times 10^{-6}$ | $2.5 \times 10^{-6}$ | 1,360 | 7.3 | 1.3 |
| 0.3–0.6 | 3.16 | 26.89 | 31.09 | 38.86 | Clay loam | $2.44 \times 10^{-6}$ | – | 1,400 | 7.42 | 1.37 |
| 0.6–0.9 | 3.10 | 24.25 | 33.73 | 38.92 | Clay loam | $2.37 \times 10^{-6}$ | – | 1,450 | 7.48 | 1.43 |

permanent wilting point were found to be 32.5, and 19.2%, respectively.

Subirrigation treatments, established at three water table depths of 0.5 (WT0.5), 0.7 (WT0.7) and 1.0 m (WT1.0) in addition to a free drainage (FD) system were examined in this study.

Except for the levels of water table management, all other inputs namely type of crop, soil condition, quality of irrigation water (1.5 dS/m), planting and harvesting dates and agronomy management were the same in all treatments. Cultivation and management practices were the same for the lysimeters and the surrounding area. These included crop type, planting and harvesting dates, soil type, fertilizer, drainage (free drainage), and leaching and irrigation schedule. The lysimeters and the field were planted with an annual alfalfa crop (*Medicago Scutellata* Var. Robinson), which is designated as a relatively tolerant crop, with a salinity threshold value of 4 dS/m (Maas and Hoffman 1977) and management allowed deficiency (MAD) of 50%. Available water was allowed to deplete to a MAD of 50% before the next irrigation. The average rooting depth of this variety is known to be about 0.5 m, in optimum growing conditions, while it is found to be at about 0.3 m in Iran.

Crops were irrigated as usual from the top in the free drainage lysimeters and through subsurface drain pipes in the subirrigation systems, except during crop establishment, such that all lysimeters were irrigated from the top to enhance root development. It means that no water was applied from the top into the subirrigation lysimeters. The depth of irrigation was calculated on the basis of soil moisture depletion (SMD) below field capacity plus a 38% leaching fraction for the free drainage lysimeters and the surrounding field area. The amount of plant water used in the subirrigation lysimeters was measured from the water uptake from the storage tank in the Marriote system, as described above. Soil moisture content was monitored at different soil depths (0.1, 0.3, 0.5 and 0.6 m) during the growing season using "WET" sensors (Delta-T Devices Ltd., UK), which had already been calibrated in the field. The time of irrigation was determined on the basis of designated MAD in the free drainage lysimeters. Irrigation intervals varied between 5 and 14 days based on evapotranspiration rate and stage of crop growing.

Leaching requirement in FD lysimeters was estimated based on electrical conductivity of irrigation water ($EC_{ir}$) and crop threshold value ($EC_{th}$). But in subirrigation lysimeters, leaching was done when the average ECe of soil in the root zone exceeded $EC_{th}$. Also, drainage water was collected from lysimeters in order to measure the quantity and quality of drainage effluent. ECe of soil was measured at different depths (0.2, 0.4, 0.6 and 1.0 m) during the growing season by in situ salinity sensors (Delta-T Devices Ltd. UK). The crop was cut in different treatments, whenever forage was at 25% flowering stage. Statistical *F* test method was used to compare and evaluate different treatments.

## Results and discussions

### Climatic data

Climatic condition was approximately similar in both years. The average monthly climatic data during the growing season is presented in Table 2. The air temperature in the months of May, June and July were slightly higher than the long-term average.

### Soil moisture

Figure 3 shows the average soil moisture variations in FD lysimeters between irrigation intervals, whereas soil moisture contents in subirrigation systems remained constant during the growing season. The collected data indicate that the soil moisture content was gradually reduced in free drainage lysimeters, and it was often lower than the corresponding soil moisture in subirrigation systems, especially in the last few days prior to the next irrigation events. In FD lysimeters, soil moisture content at 0.1 and 0.3 m depths varied between 21–34 and 25–33.2% during irrigation intervals, respectively. However, in subirrigation lysimeters, measured soil moisture content remained relatively constant i.e., 31 and 34.5% for WT0.5, 28 and 33% for WT0.7, 21 and 24% for WT1.0 for the soil depths of 0.1 and 0.3 m, respectively. Fausey and Baker (2003) stated that water supplied to crops during the entire growing season through subirrigation systems can result in yield increase by minimizing moisture stress.

### Soil salinity

The data presented in Fig. 4 show the variations of soil $EC_e$ for different treatments. Soil ECe in FD treatment did not exceed the crop threshold value (4 dS/m) throughout the growing season (Fig. 4a). However, it was increased by the depth, due to leaching of salts to lower depths. The soil ECe was observed to be higher at the surface compared with the adjacent lower layers, which could be attributed to the high evaporation.

In subirrigation treatments, in which no water was applied from the soil surface, the soil salinity profile was only affected by the upward flux from water table. Soil salinity levels at different depths (0.2, 0.4, 0.6 and 1.0 m) increased during the experimental period and an average ECe of the root zone exceeded crop threshold value (4 dS/m) after the first forage harvest (Fig. 4). At this stage, leaching was performed to lower the soil's salinity level. The $EC_e$ at different depths was increased with a relatively higher rate in WT0.5 as compared to WT0.7 and WT1.0. Shallower water table level in subirrigation lysimeters resulted in more upward flux and consequently more salt accumulation at the top layer (Fig. 4b). The same trend was also observed in WT0.7 treatment (Fig. 4c), except with a

**Table 2** Average monthly climatic data during the growing season

| Month | Average | | | | | |
|---|---|---|---|---|---|---|
| | Rainfall (mm) | 20-Year average rainfall (mm) | Evaporation (mm/day) | 20-Year average evaporation (mm/day) | Mean temperature (°C) | 20-Year average temperature (°C) |
| March | 12 | 15.2 | 6.1 | 5.7 | 23.9 | 24.4 |
| April | 5 | 4.3 | 6.6 | 6.2 | 26.3 | 27.2 |
| May | 2 | 2 | 7.8 | 6.9 | 33.5 | 31.2 |
| June | 0.5 | 0 | 9.3 | 8.5 | 38.2 | 36.5 |
| July | 0 | 0 | 11.5 | 10.3 | 40.1 | 38.6 |

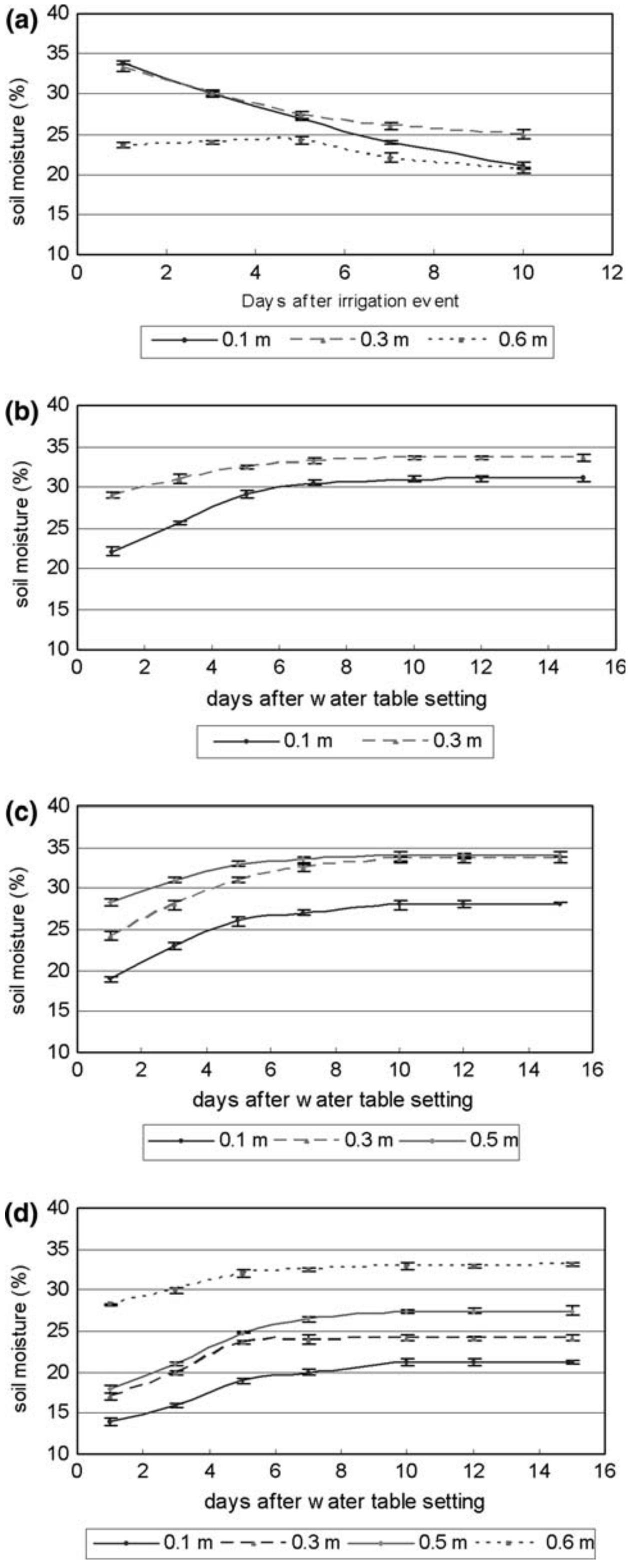


**Fig. 3** Average soil moisture in FD (**a**), WT0.5 (**b**), WT0.7 (**c**) and WT1.0 (**d**)

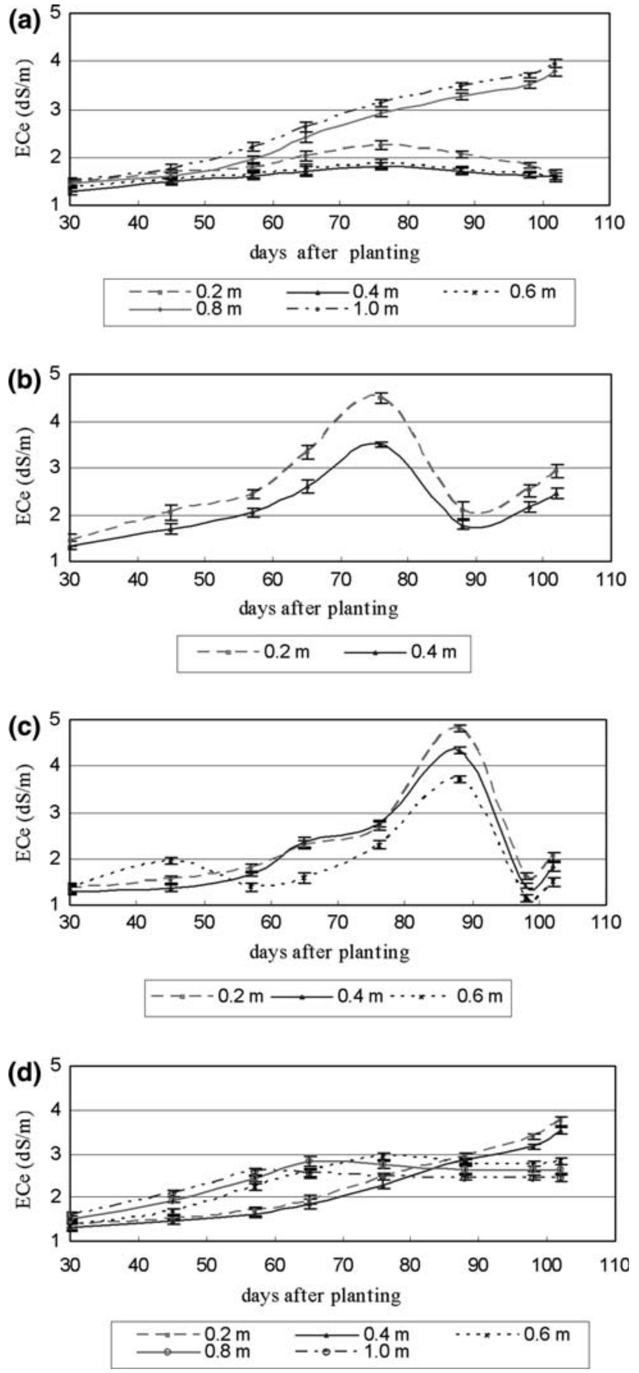


**Fig. 4** Soil salinity variations during the growing season in FD (**a**), WT0.5 (**b**), WT0.7 (**c**) and WT1.0 (**d**) lysimeters

lagged time period. Figure 4d shows that the $EC_e$ at different depths in WT1.0 never exceeded crop threshold value throughout the growing season. These results are supported by the results of Patel et al. (1999) in which soil salinity profile was developed under a subirrigation experiment using brackish water.

Figure 5 shows the soil salinity variations at the soil surface (0-0.01 m depth) in subirrigation treatments during the growing season. A high value of $EC_e$ was observed at the soil surface in subirrigation treatments after planting. It should be noticed that the saline crust was very thin and its

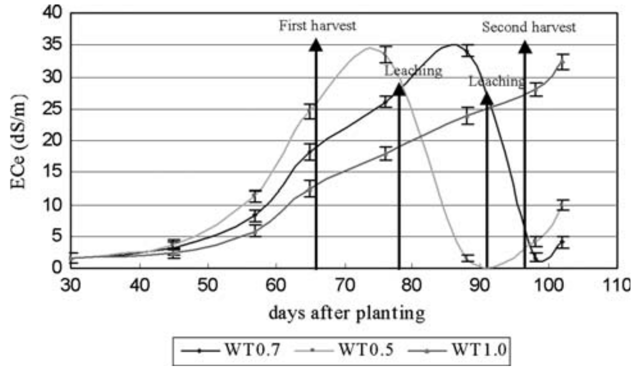


**Fig. 5** Soil salinity variations at the soil surface in subirrigation treatments during the growing season

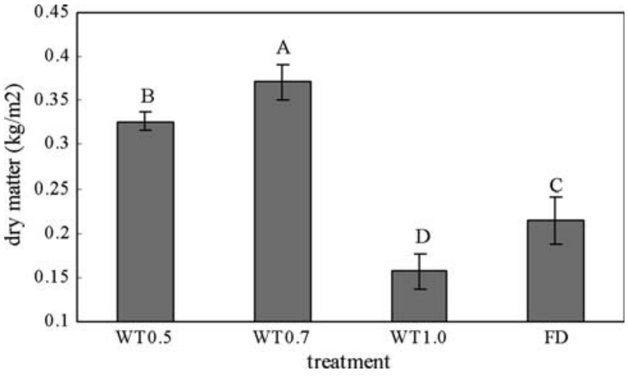


**Fig. 6** Average forage dry matter in different treatments

formation process was very slow. The average thickness of saline crust, which was measured to be approximately 1 cm, could not threaten plant growth, as no roots are active in this thin layer.

Irrigation water was applied to compensate for soil moisture deficit and leaching requirement in FD treatment. However, the applied water in subirrigation lysimeters was limited to establish and maintain the water table at the proposed levels, in addition to leaching requirements. The data presented in Table 3 indicate that the average irrigation water applied in WT0.5, WT0.7 and WT1.0 were 27, 45 and 75% lower compared with FD treatments, respectively, which shows that the subirrigation system can often supply crop water requirement more efficiently. Such management is especially important in semi-arid conditions with high irrigation water requirement.

The average dry matter yield for different treatments is presented in Fig. 6. The yields in subirrigation systems (WT0.5 and WT0.7) were significantly higher (52 and 73%) than the one in FD lysimeters.

Despite higher salt accumulation in WT0.5 and WT0.7 treatments, higher yield production was obtained due to sufficient moisture availability in the root zone. These results are supported by Skaggs et al. (1999), who reported 44 and 64% increase in tomato and corn yield in the subirrigation systems as compared to the free drainage system (FD), respectively. Patel et al. (1999) also reported a 59% increase in subirrigated potato yield over the global average yield. Lower aeration as well as higher levels of salinity in the root zone for WT0.5 treatment could be the reasons for a reduction in yield as compared to WT0.7 treatment. Lower yield in WT1.0 may be attributed to insufficient available moisture for crop consumption. The average root depth of annual alfalfa was measured to be about 34 cm in all treatments.

Moisture availability in the root zone of subirrigation systems not only provides the required water for the plant growth, but also moderates the adverse effects of salt stress. The results of this experiment could confirm the advantages of subirrigation over the conventional irrigation system in semi-arid areas of Iran. Accumulation of salts, however, is one of the limitations in the application of subirrigation systems in semi-arid conditions. Application of excess water to provide leaching requirement is a common practice to manage this problem. In this study, however, this practice was postponed to the time when soil salinity reached the threshold value. Such management resulted in a decrease in the volume of drain water produced (Noory and Liaghat 2009).

Water and nutrient absorption by crops in conventional irrigation systems follows a 40, 30, 20 and 10% pattern in the root zone (FAO 2002). However, this pattern is

**Table 3** Average applied irrigation water in subirrigation and FD lysimeters

| Treatment | Average | | | | |
|---|---|---|---|---|---|
| | Establishing water table level (mm/season) | Subirrigation water (mm/season) | Supplying SMD (mm/season) | Leaching (mm/season) | Total irrigation water application (mm/season) |
| WT0.5 | 225 | 383 | – | 198 | 806 |
| WT0.7 | 135 | 267 | – | 205 | 607 |
| WT1.0 | 70 | 190 | – | – | 260 |
| FD | – | – | 807 | 307 | 1,114 |

Seepage loss is neglected

reversed in subirrigation systems and more water and nutrients are taken up from the bottom layer of the root zone (Li et al. 2006; Simunek 2005; Braud et al. 2005). This process facilitates plant roots' interaction with soil layers having lower salinity. This can be explained by the fact that the flux is upward in subirrigation systems and carries salts to the upper layers. As previously mentioned, moisture content in the root zone was fluctuating in the conventional irrigation system, while it remained basically constant and close to the field capacity in subirrigation systems (WT0.5 and WT0.7). The availability of adequate moisture in the root zone for the WT0.7 treatment led to more water and mineral absorption by plant roots, which resulted in an increase in the dry matter production of alfalfa.

In this study, it was concluded that the gradual movement of water and salts to the root zone in subirrigation systems delay salt accumulation and reduce required soil leaching frequency. Despite salt accumulation on the soil surface in subirrigation treatments, not only no yield reduction was observed, but also a significantly higher dry matter production was obtained compared to the FD system.

Late seasonal rainfalls could potentially pose a threat to the subirrigation system at the end of the growing season, leaching the accumulated salts at the soil surface back to the root zone. Of course, the possibility of rainfall events is very low in semi-arid areas; however, with good time management of sowing and harvesting dates, the threat of late season rainfalls could be avoided. In case of high rainfalls, the drain outlets could be operated freely, and by application of some additional irrigation water, excess salts could be leached out.

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