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The Use of Clay Deposits in Drip Irrigation System for Water Conservation

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Abstract

Water research studies in Saudi Arabia clearly showed sever depletion of groundwater. Therefore, the scientifically applied research program related to water saving and conservation in agriculture is essential, where agricultural activities account for more than 85% of the total water consumed. This study aims to investigate the effect of four irrigation levels, two irrigation methods and three clay deposits on water use efficiency (WUE) of squash and the distributions of salts and roots in sandy calcareous soils. A field experiment was conducted at the college experimental station in 2002 and 2003 seasons. It consists of three clay deposits, three rates (CO=0, C2 = 1.0 and C3 = 2.0%), four irrigation levels (T1 = 60, T2 = 80, T3 = 100 and T4 = 120 % of Eto) using surface (IM1) and subsurface (IM2) drip irrigation.

Results indicated that squash fruit yield was significantly increased with the increase in irrigation water level for each season. Generally, WUE values were increased as linearly with applied irrigation water and decreased at the highest irrigation level. Types of clay deposits significantly affected fruit yields compared with the control. The yield increase was 12.8, 8.35 and 6.4% for Khulays, Dhruma and Rawdat clay deposits, respectively. The differences between surface and subsurface drip on fruit yields and WUE were also significant. Results indicated that moisture content of subsurface treated layer increased dramatically, while salts were accumulated at the surface and away from the emitters in subsurface drip irrigation. Intensive root proliferation is observed in the clay amended subsurface layer compared with non amended soil. The advantages of subsurface drip irrigation were related to the relative decrease in salt accumulation in the root zone area where the plant roots were active and water content was relatively higher.

Keywords: Drip irrigation; Subsurface drip irrigation; Clay deposit; Squash yield; Sandy soils.

Introduction

Field water management practices are the most influential factors affecting crop yield particularly in irrigated agriculture in arid and semiarid regions. Sandy soils are particularly critical for water management in irrigated agriculture because of their low water holding capacity and low clay contents. The productivity of these soils is limited by high infiltration rate, high evaporation, low fertility level, low water holding capacity and low organic matter content. Synthetic soil conditioners were used to alleviate some of these constrains (Choudhary et al., 1998; Al-Omran et al., 1987; Al-Harbi et al., 1999). Due to their high cost and insufficient longevity, the use of natural amendments could be another alternative to improve the chemical and physical properties of these soils (Al-Omran et al., 2002 & 2004). The use of these deposits may increase the productivity, especially in the areas where these materials are available naturally in abundance and inexpensive (Abou-Gabal et al., 1990). The sustainable use of scarce water resources in Saudi Arabia is a priority for agricultural development. The pressure of using water in agriculture sector is increasing to create ways to improve water use efficiency and taking a full advantage of available water. Therefore, adoption of modern irrigation techniques is needed to be emphasized to increase water use efficiency. Drip irrigation is the most effective way to convey directly water and nutrients to plants and not only save water but also increases yields of vegetable crops (Tiwari et al., 1998a,b; Tiwari et al., 2003). Phene et al. (1991) studied the distribution of roots under sweet corn as a function of drip placement and fertilization treatment. They reported differences between surface and subsurface drip irrigation on sweet corn rooting system in the top 45 cm. High root length density was observed below 30 cm in the subsurface drip irrigation than in the surface drip. Ibrahim et al. (1987) reported high and intensive tomato root proliferation in the organic manure layer added as a thin subsurface layer in sandy soils. They added that the highest WUE of tomato was obtained from the subsurface application of manure under drip irrigation system. Recently, Bryla et al. (2003) reported that drip irrigation improved production and water use efficiency of faba bean in California using different levels of irrigation based on percentage of evapotranspiration. Ayars et al. (2001) reported from their studies on subsurface drip irrigation and furrow irrigation in the presence of shallow saline ground water that yield of the drip irrigated cotton improved during the 3-year study, while that of furrow irrigated cotton remained constant. Also, tomato yields were greater under drip irrigation than under furrow irrigation in the same study from the first year. Sammis (1980) found that, drip irrigation allows uniform delivery of water and nutrients directly to the plant root zone. This can increases N use efficiency over other irrigation methods (Miller et al.,1981). Lamm and Trooien (2003) reported that a successful application of subsurface drip irrigation for 10 years in Kansas, USA reduced the irrigation water use for corn by 35 – 55% compared with traditional forms of irrigation. Thompson and Doerge (1995) reported that under subsurface drip irrigation a target of soil water tension of no wetter than 6.5 kPa is appropriate for subsurface trickle irrigated Romain lettuce. Phene et al. (1987) reported that subsurface drip irrigation improved WUE of tomato plants. Therefore, the purpose of this study was to investigate the influence of irrigation levels and surface and subsurface drip irrigation on squash fruit yield, water use efficiency, water and salts distributions and rooting pattern in irrigated sandy calcareous soils amended with different rates of natural clay deposits.

Materials and Methods

A Field experiment was conducted at the College of Agricultural Research Station at Dirab, (24° N, 4625°34 E), 40 km southwest of Riyadh, Saudi Arabia, during the months of April-June for two seasons (2002 and 2003). Selected properties of the soil and irrigation water were determined by the standard procedure (Page et al., 1982). The soils are non saline, calcareous ($CaCO_3$ ranges from 269 to 353 gkg-1 soil) and sandy in texture, while irrigation water has high salt content (TDS=3300 mg/l) and moderate alkalinity (SAR=7.69). Natural clay deposits were collected from different regions in Saudi Arabia e.g western region (Khulays) and central region (Dhruma and Rawdat areas). Deposit samples were prepared by grinding and sieving through a 2mm sieve. Some physical and chemical characteristics of representative samples are presented in Table 1. The three amendments (Khulays, Dhruma and Rawdat) were applied in each row as a subsurface thin layer at a depth of 15 - 20 cm and at rates of 1 and 2% of the soil. The experimental layout was presented in Figure 1. It included surface (S) and sub-surface (SS) drip irrigation, with four irrigation levels at 60 (T1), 80 (T2), 100 (T3), and 120% (T4) of the estimated crop evapotranspiration (Eto) (Al-Omran et al., 2004). The 30 m x 30 m field plot was divided into four equal subplots for the irrigation levels (T1, T2, T3, and T4). Surface and subsurface drip irrigations were installed in each half of the subplots, respectively. Drip tubing (GR type, 16 mm diameter) with 40 cm emitter spacing built in (delivering 4 Lhr^{-1}) was used in the surface and the subsurface drip irrigation treatments. The experiment was laid out following the complete randomized block design with three replicates for each treatment (Fig. 1). Each treatment consists of 7 drippers (2.8 m tubing) and the distance between two rows was about 1 m. Squash (*Cucurbita pepo* cv. Mashael) seeds were sowed on April, 10th, 2002 for the first season and April 1st, 2003 for the second season with three seeds at each dripper. Irrigation by the surface drip system was commenced after planting in all treatments for the establishment (one to two leaf stage). Then, surface and/or subsurface drip irrigation was continued every other day till the end of the experiment. The total amounts of fertilizer are 200 kg ha^{-1} N, 150 kg ha^{-1} P_2O_5 , and 120 kg ha^{-1} K_20 . About half of P_2O_5 and K_20 were applied pre-planting while the remaining amounts were applied through the irrigation systems. Uniform fertigation was used to deliver the fertilizer requirements using (N, P, K) liquid fertilizer in all treatments. The second season plantations were essentially commenced on the previous treatments at the same site. Nine soil samples were collected before irrigation from the root zone area on a grid bases (15 cm apart) around the dripper at three growth stages namely vegetative stage, flowering stage and at the end of the season. Samples were collected from the lower and higher amendment rate treatments and then water contents were determined by gravimetric method after oven drying at 105°C. Salt distributions were assessed by measuring EC in 1:1, soil to water extract, then contour maps for water and salt distributions in the root zone area were introduced using Surfer Software (Golden Software, 2000) for the collected soil samples. Measurements of special distribution of roots were carried out for all treatments at the end of the experiment. The measurements were conducted through trench profile technique according to Bohm (1979). Trenches were excavated to a depth of 50 cm, and then roots were counted through a grid and illustrated graphically in relation to the position of the added clay layer and the drip method.

Results and Discussion

Results of analysis of variance for the squash fruit yield and water use efficiency (WUE) as affected by water regime, surface and subsurface drip irrigation and types and rates of amendments.. It was noticed that the tested parameters for the 1st and 2nd seasons were quite similar despite the fact that the 2nd season plantation was carried out on the previous treatments. This indicated a positive effect of the previous clay treatments on the soil and consequently on the yield and WUE of squash. Data showed that differences due to water regime, surface and subsurface drip irrigation and the interactions between water regime and irrigation methods were highly significant (at 1% level) for both squash fruit yield and WUE. Differences in WUE and squash fruit yields due to amendment rates and the interactions between amendment rates and water regime or irrigation methods were also significant (at 1% or 5% levels) whereas the interaction between amendment types and rates was not significant. Data also showed that differences due to amendment types and the interaction between water regime and amendments or the irrigation methods and amendments were not significant. These results reflect the positive effect of water regimes, surface and subsurface drip irrigation and amendment rates on squash fruit yield and WUE. The results are further elaborated in order to evaluate the effect of each treatment on squash fruit yield and WUE. Effect of amendments types, irrigation regimes, irrigation methods and the amendment rates on squash fruit yield and WUE are presented in Table 4 and graphically illustrated in Figure 2 for the second season. It indicated that at high irrigation levels (non-stressed T4 and T3 treatments), fruit yield were high and decreased significantly at low irrigation levels (stressed, T2 and T1 treatments) in either the 1st or the 2nd seasons. The average yield of the 1st and 2nd seasons increased about 12.6% in the T4 treatment when compared with T3 treatment, whereas average yield decreased in the T2 and T1 treatments by about 33.4 and 40.7%, respectively. A similar trend was found with WUE; it increased about 7.53% in the T4 treatment and decreased 31.9 and 33.1% in the T2 and T1 treatments, respectively when compared with T3 treatment. The drastic reduction in yield and WUE in the stressed treatments could be due both to the unavailability of water and the possible accumulation of salts in the root zone area as a result of using quite high saline irrigation water (3300 ppm TDS) without proper leaching.

The results showed that amendment types significantly affected fruit yield when compared with control but the differences between the studied amendments were not clear. There was decrease in yield and WUE in the 2nd season compared with the 1st season. Khulays deposit shows higher average yield and WUE in the 1st and 2nd seasons followed by Dhruma and Rawdat, respectively. The yield increase was 12.81%, 8.35% and 6.40% for Khulays, Dhruma and Rawdat, respectively when compared with the control. The differences could be due to in the clay deposit characteristics (Table 1) and variation in $CaCO_3$ content, ECe, CEC and the dominant clay minerals. Khulays deposit showed some desired characteristics such as low $CaCO_3$, high CEC and the dominance of smectite clays, whereas it has relatively high original salinity which could be leached out of the root zone area before cultivation. The amendment rates significantly affected squash fruit yields in the 1st season while differences in the 2nd season were not significant under the experimental conditions. The average fruit yield was increased by 13.4% and 15.0% at 1 and 2% amendment rates when compared with control. Such increase in yield could be due to the improvement of sandy soil characteristics particularly the available water content and nutrient status (Table 1). Also, differences in WUE due to amendment rates in either 1st or 2nd seasons were not significant. Differences in squash fruit yield due to irrigation methods in the 1st season were significant and the yield increase due to subsurface drip irrigation was about 19.9% over the surface drip irrigation. Also, WUE in the 1st season was significantly higher with the subsurface drip irrigation compared with the surface drip. It appears that subsurface drip irrigation creates more suitable conditions in the root zone area for plant growth and productions. This is in agreement with the results reported by Lamm and Trooien (2003).

Data of water and salt distributions in the root zone area for all treatments were graphically illustrated on a surface contour bases and data of selected treatments (T3) were presented in Figures 3 and 4. It indicated that water distributions show specific distribution patterns in the amended soil when compared with non amended soil (control) in both surface and subsurface drip irrigation. Such distribution pattern depends on the type and rate of amendment in the subsurface treatment. In non amended soil, water content was generally low (about 2-1%) on the surface and increased gradually with depth without clear distribution trend (5-7%). There was no clear difference between surface and subsurface drip irrigation in non amended soil where soil profile was not modified. This trend could be due to water evaporation from the surface and hence decrease water content in the surface layer and the gradual increase with depth that related to the capillarity of the soil of the control treatment.The T4 treatment showed relatively high water content below 30 cm depth indicating deep percolation and partial losses of water below root zone. This trend was not clear in T2 and/or T1 treatments. In amended soil water content was quite high at either surface or the subsurface drip irrigation treatment (Fig. 3) particularly in the amended subsurface layer (Pw = 10-12% in the soil treated with Khulays clays). It was clear that water seems to be stored in the treated layer with no or little percolation below 30 cm depth. The surface layer of the subsurface drip treatment was relatively dry and it seems to be uniform in dryness compared with the surface irrigation where dryness seems to be on the sides. Therefore, applications of clay deposits to sandy soils modifies the distribution of water content in the root zone area where water could be retained by clays applied to the subsurface layer. The desired characteristics of clay deposits could be reflected on the improvement of soil texture, structure, swelling, increasing CEC and soil water retention, hence resulted improved soil water contents in the squash root zone.

Soluble salt distributions (EC, dS/m) in the root zone area showed an adverse trend when compared with water distributions; it was high on the surface and decreased gradually with depth to the lowest values (at 15-30 cm depth). Amended soil with clay deposits (Rawdat deposit) indicated clear different trend particularly in the amended layer (about 20 cm depth). Salt concentration was relatively low in the amended layer while it accumulated on the surface in the subsurface drip irrigated soil and around the emitter in the surface drip irrigated soil. Salt accumulation appears to be reversibly related to water distribution in either surface or the subsurface drip. Again it appears that the subsurface amended layer have the lowest salt concentrations without clear differences when compared with the control. Therefore, increasing water content in the clay amended layer under subsurface drip seems to alleviate the harmful effect of salts and create more suitable conditions for root growth.

Conclusion.

The study concluded that management practices which include subsurface drip irrigation and the subsurface applications of natural deposits have high potential for improving squash fruit yield and WUE. Types of clay deposits significantly affected fruit yields compared with the control. The yield increase was 12.8, 8.35 and 6.4% for Khulays, Dhruma and Rawdat clay deposits, respectively. Clay amendment application as a subsurface layer to sandy calcareous soils increased water content, decrease soil salinity and improve the distribution of roots in the treated layer. The advantages of subsurface drip irrigation were related to the relative decrease in salt accumulation in the root zone where the plant roots were active and water content was relatively higher.

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