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Use of Clay Deposits in Water Management of Calcareous Sandy Soils Under-surface and Sub-surface Drip Irrigation

استخدام الرسوبيات الطينية في إدارة مياه الري للترب الرملية الكلسية تحت ظروف الري بالتنقيط السطحي وتحت السطحي

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Abstract: The objective of this study was to investigate the effect of irrigation (levels & methods) and type of clay deposits on lettuce yield, water use efficiency WUE and the distributions of soil moisture and salts in the root zone of sandy calcareous soils. A field experiment was conducted at the college experimental station in 2002-2003. It consists of three clay deposits, three rates (0, 1.0, and 2.0%), and four total irrigation applied water levels, 360 mm (T1), 520 mm (T2), 635 mm (T3), and 822 mm (T4), using surface and subsurface drip irrigation. Results indicated that yield was significantly increased with the increase of irrigation level, whereas WUE significantly decreased with increase of irrigation level. The average yield increased by 9.30% in a high irrigation level compared to a moderate irrigation level, and decreased by 14.2% at the more stressed irrigation level. WUE decreased by 49.0% at a moderate irrigation level and decreased by 55% at a high irrigation level. Types of clay deposits did not affect the yield; however, the yield was significantly affected by amendment rates. The differences between surface and subsurface drip on yields and WUE were also significant. Results indicated that the moisture content of the subsurface treated layer increased dramatically, while salts were accumulated at the surface and away from the emitters in subsurface drip irrigation. The advantages of surface drip irrigation were related to the relative decrease in salt accumulation in the root zone area where the plant roots were active and the water content was relatively high.

Keywords: *Drip irrigation, clay deposit, lettuce yield, sandy soils*

المستخلص: هدفت هذه الدراسة إلى البحث في والتحقق من تأثير عملية الري من حيث المعدلات وطريقة الري (سطحية وتحت سطحية) ونوع الرسوبيات الطينية، كمحسنات للتربة، على الحصيلة الإنتاجية لنبات الخس، وكفاءة استخدام المياه، وتوزيع الرطوبة والأملاح في طبقة الجذور لتربة رملية كلسيه. ولتحقيق هذا الهدف تم إجراء تجربة حقلية في محطة البحوث الزراعية بكلية الزراعة، جامعة الملك سعود، خلال الفترة 2002-2003. اشتملت التجربة على إضافة ثلاثة رسوبيات طينية للترب الرملية الكلسية بثلاث معدلات (صفر، 1%، 2%)، وأربع مستويات للمياه المستخدمة في الري الإجمالي (360 ملم (T1)، 520 ملم (T2)، 635 (T3)، 822 ملم (T4)، باستخدام طريقة الري بالتنقيط السطحي والتنقيط تحت السطحي. وقد دلت نتائج الدراسة على أن الحصيلة الإنتاجية لنبات الخس قد سجلت زيادة ملحوظة وذات دلالة مع زيادة مستوى الري، بينما سجلت كفاءة استخدام المياه انخفاضا ملحوظاً مع زيادة مستويات الري. ولقد أرتفع متوسط الإنتاج بنسبة 9.30% في حالة مستويات الري المرتفعة مقارنة بمستويات الري المتوسطة، وانخفض بنسبة 14.2% في حالة مستويات الري المنخفضة. ولقد انخفضت كفاءة استخدام المياه بنسبة 49% في حالة مستويات الري المتوسطة وانخفضت بنسبة 55% في حالة مستويات الري المرتفعة. بالإضافة لذلك، دلت الدراسة على أن الانواع المختلفة للرسوبيات الطينية لم يكن لها تاثير على الإنتاج، إلا أن الإنتاجية قد تأثر بصورة ملحوظة وذات دلالة مع التغير في معدلات إضافة هذه المحسنات. كما دلت الدراسة على أن الفروقات بين الري بالتنقيط السطحي والتنقيط تحت السطحي كان ذو دلالة ملحوظة على الإنتاج وعلى كفاءة الاستخدام. ودلت نتائج الدراسة على أن نسبة الرطوبة في الطبقات تحت السطحية التي تم معاملتها قد زادت بدرجة كبيرة جداً، بينما ترسبت الأملاح على السطح وبعيداً عن المنقطات في الري تحت السطحي. وتم ربط فوائد الري بالتنقيط السطحي بالانخفاض النسبي في ترسب الأملاح في منطقة نطاق الجذور، حيث تكون جذور النبات نشطة ومحتوى المياه مرتفع نسبياً.

كلمات مدخلية: *ري بالتنقيط، رسوبيات طينية، إنتاج الخس، تربة رملية.*

Introduction

The sustainable use of scarce water resources in Saudi Arabia is a priority for agricultural development. The pressure of using water in the agriculture sector is increasing to create ways to improve water use efficiency and take full advantage of the available water. Therefore, adoption of modern irrigation techniques must be emphasized to increase water use efficiency. Drip irrigation is the most effective way to directly convey water and nutrients to plants; it not only saves water but also increases the yield of vegetable crops Tiwari, et al., (1998a, b); Tiwari, *et al.*, (2003). Bryla, *et al.* (2003) reported that drip irrigation improved production and water use efficiency of faba beans in California using different levels of irrigation based on the percentage of evapotranspiration. Ayars, *et al.* (2001) reported in their studies on subsurface drip and furrow irrigation in the presence of shallow saline groundwater that the 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. 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 more traditional forms of irrigation. The purpose of this study was to investigate the influence of irrigation levels and surface and subsurface drip irrigation on lettuce yield, water use efficiency, water and salt distributions 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°25´ N, 46°34´ E), 40 kilometers South-West of Riyadh, Saudi Arabia. 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., the western (Khulays) and central regions (Dhruma and Rawdat areas).

Deposit samples were prepared by grinding and sieving through a 2-mm sieve, and then analyzed for their physical and chemical properties (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 experiment included surface (S) and sub-surface (SS) drip irrigation, with four irrigation water levels applied 360 mm (T1), 520 mm (T2), 635 mm (T3), and 822 mm (T4) for the whole season. The 30 x 30 m^2 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 L/hr) 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. Each treatment consists of 7 drippers (2.8 m tubing) and the distance between every two rows was about 1 m. Lettuce (Lactuca Sativa cv. Parris Island) seeds were sown in Jeffy-7 pots on 29 September, 2002, kept in a green house until 17 of December, and then transplanted to the field with three seedlings at each dripper. Irrigation by the surface drip system was commenced after transplanting in all treatments for the establishment. 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} P2O5, and 120 kg/ha^{-1} K20. Uniform fertilization was used to deliver the fertilizer requirements using (N, P, K) liquid fertilizer in all treatments.

Nine soil samples were collected before irrigation from the root zone area on a grid base (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 the gravimetric method after oven drying at 105 C°. Salt distributions were assessed by measuring EC in 1:1 soil to water extract, then three dimension figures for water and salt distributions in the root zone area were introduced using MATLAB software for the collected soil samples. Heads of lettuce were picked at the end of the season (March 22, 2003), weighed, and the total yield was determined.

Table 1. Some physical, chemical, mineralogical and fertility characteristics of the clay deposits used in the experiment (SAR Sodium Adsorption Ratio , CEC Cation Exchange Capacity. ++++ High , ++ Medium , + Low , Q quartz , F Feldspars).

	Dhruma	Khulays	Rawdat
	Physical and Chemical properties		
Sp %	63.0	53.0	74.0
EC_e dSm^{-1}	7.15	22.0	3.35
pH soil paste	7.97	7.25	7.59
SAR	16.10	2.30	0.86
$CaCO_3$ gKg^{-1}	30.0	30.0	420.0
O.M. gKg^{-1}	19.3	29.0	88.7
CEC Cmol Kg^{-1}	29.8	39.6	21.6
Clay %	60.0	60.0	59.0*
Silt %	12.0	36.0	40.0
Sand %	28.0	4.0	1.0
Texture	Clay	Clay	Clay
	Clay Mineralogy		
Smectite	++	++++	++++
Kaolinite	++++	++	+
Vermiculite	-	+	+
Accessory Minerals	Q	Q,F	Q
	Fertility Status		
N	-	-	-
P $mgKg^{-1}$	2.9	2.0	21.4
Fe $mgKg^{-1}$	14.87	12.92	155.0
Zn $mgKg^{-1}$	0.97	1.30	1.97
Mn $mgKg^{-1}$	2.65	2.17	43.3
Cu $mgKg^{-1}$	0.84	1.35	2.98

Results & Discussions

Data show 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 yield and WUE. Differences in WUE and 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 lettuce yield and WUE.

Table 2. Effect of clay deposits (type and rates), irrigation regimes and methods on Lettuce yield (ton ha-1) and WUE (kg m-3).

Treatments	Yield (ton ha^{-1})	WUE (kg m^{-3})
	Effect of clay deposits type	
Dhruma	7.52	9.68
Khulays	7.17	9.96
Rawdat	7.65	9.32
$LSD_{0.05}$	n.s.	n.s.
	Effect of irrigation water regimes	
T1	6.82 C	14.88 A
T2	7.79 AB	9.60 B
T3	7.24 BC	7.52 C
T4	7.95 A	6.64 C
$LSD_{0.05}$	0.66	0.88
	Effect of irrigation methods	
Surface drip	9.49 A	12.32 A
Subsurface drip	5.40 B	7.00 B
$LSD_{0.05}$	0.46	0.60
	Effect of amendment rates	
Control	6.79 C	8.52 C
1%	7.39 B	9.64 B
2%	8.16 A	10.8 A
$LSD_{0.05}$	0.57	0.56

The results are further elaborated in order to evaluate the effect of each treatment on lettuce yield and WUE. Effect of amendment types, irrigation regimes, irrigation methods and the amendment rates on lettuce yield and WUE are presented in Table 2. It indicated that at high irrigation levels (non-stressed T4 and T3 treatments), yield were high and decreased significantly at low irrigation levels (stressed, T2 and T1 treatments). The average yield increased about 12.8% in the T2 treatment when compared with T1 treatment, whereas average yield decreased in the T2 and T1 treatments by about 2.8 and 16.6%, respectively, compared to non stressed treatment T4. WUE decreased with non-stressed treatment by 35.4, 49.8 and 55.4% at T2, T3 and T4 compared to the stressed treatment T1. The drastic reduction in WUE could be due to the increase of the amount of water used and the possible accumulation of salts in the root zone area as a result of using irrigation water with quite high salinity (3300 TDS) without proper leaching which results in lower yield from T1.

The results showed that amendment types significantly affected yield when compared with control, but the differences between the studied amendments were not significant. The yield increase was 12.6%, 10.75% and 5.6% for Rawdat, Dhruma and Khulays, respectively, when compared with the control. The differences could be due to the differences in the clay deposit characteristics and to the differences 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 average yield was increased by 8.9% and 20.1% 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. Differences in lettuce yield due to irrigation methods were significant and the yield increase due to surface drip irrigation was about 43.4% over the subsurface drip irrigation. Fruthermore, WUE was significantly higher with the surface drip irrigation compared with the subsurface drip irrigation. It appears that surface drip irrigation created more suitable conditions in the root zone area for plant growth and productions.

Data of salt distribution (Figure 1) in the root zone area for all indicate that salt distribution shows specific distribution patterns in the amended soil when compared with non-amended soil (control) in both surface and subsurface drip irrigations. Such distribution patterns depend on the type of amendment, and amendment rates in the subsurface treatment. In non-amended soil, water content (not shown) was generally low (about 2-1%) on the surface and increased gradually with depth without a clear distribution trend (5-7%).

There was no clear difference between surface and subsurface drip irrigation in non-amended soil where the 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 T1 treatment showed relatively high water content below 30 cm depth indicating deep percolation and partial losses of water below the root zone. This trend was not clear in T3 and/or T4 treatments. The amended soil water content was quite high either for the surface or the subsurface drip irrigation treatment 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 the 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 may be reflected on the improvement of soil texture, structure, swelling, increasing cation exchange capacity and soil water retention, hence improved soil water contents in the root zone.

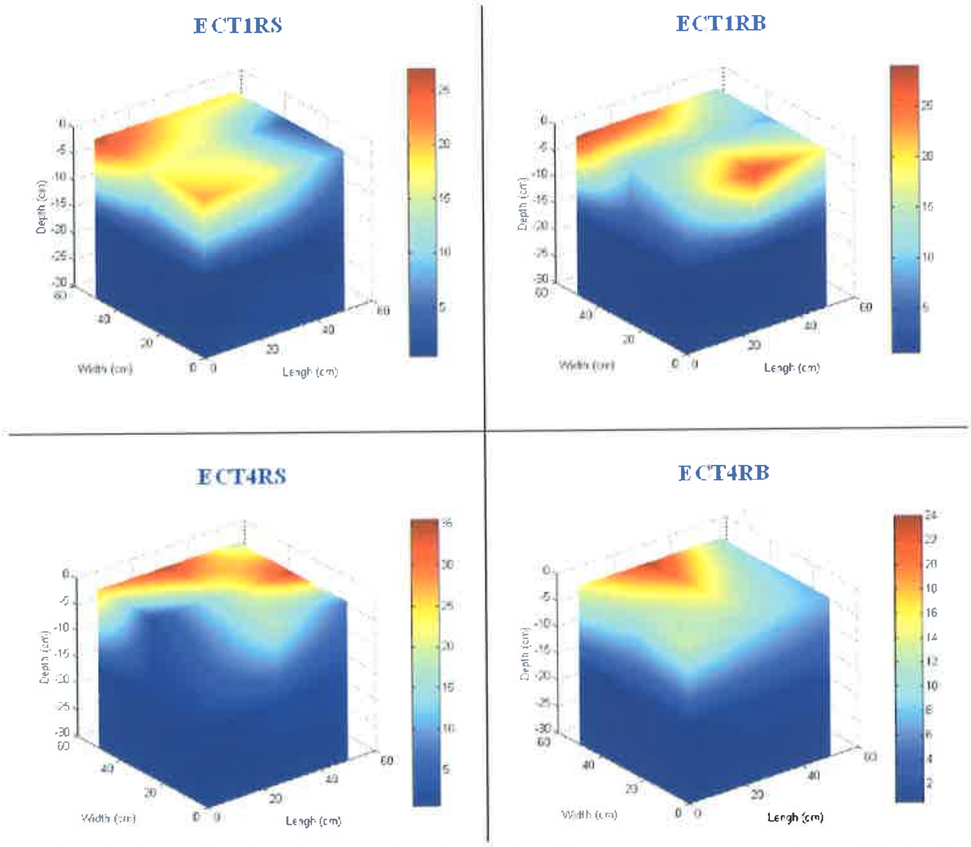

Fig. 1. Salt distributions (EC, dS/m) in the root zone area in surface and subsurface drip irrigation as affected by amendments.

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