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Effect of Water Quality and Gel-Conditioner Rate on Intermittent Evaporation

A.M. Al-Omran and A.A. Shalaby
Soil Science Department, College of Agriculture,
King Saud University, Riyadh, Saudi Arabia

Abstract. The joint effect of different rates of gel-forming conditioner (commercially called Culture Plus) and water quality on aggregation and intermittent water evaporation from sandy soils was investigated. Twenty-two mm of water was applied every seven days to each column during three weeks of the experiment. The aggregation index significantly increased by 2.23, 10.86, and 17.06% and the available water increased by 51.0, 73.0, and 122.0% as a result of adding 0.2, 0.4, and 0.6% Culture Plus, respectively. The water absorption capacity of the conditioner decrease significantly by 59.3, 73.6 and 85.5% with the increase in EC of water to 1, 2, and 4 dS m^{-1}, respectively. The Culture Plus rate of 0.4% had significantly lower evaporation compared to other treatments at different water quality, which resulted in higher water conserved. Also, the result showed that, at the first cycle, there was no significant difference between water quality at specific rate of Culture Plus.

Introduction

The soils in eastern and central regions of Saudi Arabia are calcareous, sandy, and low in fertility status [1] and characterized by their low water holding capacity and excessive deep percolation. The use of soil amedments (super absorbents) in particular soil conditioners, may alleviate some of the above limitations. Super absorbent materials are capable of absorbing water hundreds of times their own weight. These polymers were found to increase soil water holding capacity [2] and swelling [3 and 4], while decreasing infiltration [5 and 6]. Moreover, these super absorbents were found to decrease sorptivities of some sandy soils [7], improve crop water use efficiency [8 and 9], suppress evaporation [2, 3, and 10], and increase aggregates stability of the soils [3, 11, and 12].

In Saudi Arabia the average annual rainfall is 100 mm and water resources for agriculture are limited to relatively medium to saline ground water [13]. In addition, the gross water requirement will be higher to compensate the increased leaching requirements as a result of using saline ground water. The combined effect of super absorbents and saline water on soils has been reported in many studies. Helalia and

Letey [14] found that the polyaccrylamide soil conditioner called "PAM" at rate of 5 mg L^{-1} increased flocculation of soils with different water quality. Mustafa *et al.* [6] found that soils in general tend to decrease in swelling and increase in water penetrability and diffusivity with increase in water salinity and the decrease in polyaccharides soil conditioner (commercially called Jalma) rate. In previous studies Al-Omran *et al.* [15] reported on the effect of different conditioners and water salinity on cumulative evaporation.

The main objective of this study is to investigate the joint effect of "Culture Plus" gel conditioner and differing water quality on aggregation index and evaporation.

Materials and Methods

Calcareous bulk topsoil (0–0.25 m) sample (Typic Torripsamments) was collected from the College of Agriculture Experimental Station at Dirab, Saudi Arabia. The sample was air-dried and passed through 2-mm sieve. Its properties, determined using standard procedures [16], were percentage of clay (5%), silt (5%), sand (90%), organic matter 0.12%, $CaCO_3$ (32%), pH (paste) (8.1), EC_e (1.1 dS m^{-1}), and SAR (0.9). The conditioner used is commercially called Culture Plus*. Three kilograms of soil subsamples were thoroughly hand mixed with predetermined amount of Culture Plus as a gel. The mixture was dried and passed through a 2-mm sieve. Four subsamples, each containing 0.0, 0.2, 0.4, and 0.6% of dry Culture Plus, were prepared for each water quality treatments. In addition to distilled water, three synthetic water solutions of a mixture of NaCl-$CaCl_2$ were used in the experiment. The electrical conductivites (EC) of the water solution were 1, 2, and 4 dS m^{-1} at sodium absorption ratio (SAR) of 10. The variables measured included: water absorption capacity of the gel, aggregation index, available water, evaporation versus time for three cycles, and soil water content and soil salinity distribution at the end of the third drying cycle.

The absorption capacity (ml gm^{-1}) of the conditioner was tested using four different water qualities. The Culture Plus (0.2 gm) was added to 100 ml of water from each treatment in 250 ml glass beaker. The beakers were covered with aluminium foil and left for 24 hours to ensure complete absorption by the conditioner. The excess water was then drained off using filter paper and weighed to determine water absorption capacity.

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*The use of trade name is for the information and convenience of the reader. Such use does not constitute an official endorsement of the product.

Aggregation index is defined as the amount of water-nondispersible silt plus clay of the soil. Twenty grams of soil sample were put into a cylinder and then filled with water. The suspension was stirred for 15 seconds, using a plunger. The silt plus clay was determined by pipette method [16]. Total silt plus clay was similarly determined using a completely dispersed sample. Pressure-cooker and pressure plate apparatuses were used to measure the moisture content at the field capacity (FC) and permanent wilting point (PWP) to determine the available water [16]. Three determinations were made at each pressure for each treatment.

Evaporation studies were made using 0.32 m long soil columns (0.05 m treated soils over 0.27 m untreated soils) packed into glass tubes, 0.40 m long with 0.059 m i.d., and closed at one end by cloth firmly held by strings. Uniform packing was achieved by adding the soil sample in small aliquots and dropping the column 10 times over a vertical distance of about 0.05 m on a level bench. The average bulk density of packed soils was 1.56 gm cm^{-3}. The soil columns were placed in a walk-in growth chamber with light intensity of 25.7 w m^{-1}, a constant temperature of 28°C and 14/10 hours day/night cycle. Twenty-two mm of water was applied weekly for three weeks. At the end of the third cycle the water content and salt distribution in each column were determined. Each treatment was replicated thrice in completely randomized design in the growth chamber. The procedure adopted was similar to that reported elsewhere [3].

Results

Aggregation index and available water

For convenience, the 0.0, 0.2, 0.4, and 0.6% Culture Plus rate may be referred to hereafter as $C_{0.0}$, $C_{0.2}$, $C_{0.4}$, and $C_{0.6}$, respectively. The aggregation index significantly increased by 2.23, 10.86 and 17.06% as a result of adding 0.2, 0.4 and 0.6% of Culture Plus, respectively (Table 1), and the available water content increased by 51, 73, and 122%. The aggregation index at the differnt synthetic water solution was about 100% with different rate of Culture Plus.

Absorption capacity

Table 2 shows the effect of water quality on the absorption capacity of the soil conditioner. The absorption capacity decreased significantly by 59.3, 73.6 and 85.3% as a function of ECs of 1, 2, and 4 dS m^{-1} respectively.

Cumulative evaporation

The cumulative evaporations for three (7-day) cycles as a function of conditioner and water quality are shown in Table 3. The results showed that $C_{0.4}$ had significantly lower evaporation than other treatments. The cumulative evaporation (E) at different water quality ranked as follows: $C_{0.0} > C_{0.2} > C_{0.6} > C_{0.4}$. The E versus time (t) relationship as affected by the rate of conditioner is shown in Fig. 1. The effect of water quality on evaporation at $C_{0.4}$is shown in Fig. 2. The effect of the water quality appeared at the third cycle only. The data showed that there was no significant difference between the water quality treatment at the same rate of Culture Plus.

The amount of water conserved by different water quality and conditioner rate is shown in Table 4. The results showed that the water quality of 4 dS m^{-1} with $C_{0.4}$ gave higher percent of water conserved than other treatments. For water quality of 4 dS m^{-1} the water conserved at the end of the first cycle increased by 68.36, 128.56, and 127.82% for $C_{0.2}$, $C_{0.4}$ and $C_{0.6}$ respectively. For the third cycle, the increase of water conserved was 62.44, 160.0, and 119%, respectively, for the same rate in sequence.

Table 1. Aggregation indices[1], water content at F.C., P.W.P. and available water as affected by "Culture Plus" rate.

Culture Plus rate (%)	Aggregation index	Watercontent at F.C.	at P.W.P.	Available water
		%		
Control	66.29	13.00	2.75	10.25
0.2	67.77	18.67	3.19	15.48
0.4	73.49	21.07	3.30	17.77
0.6	79.93	39.07	16.31	22.76
$LSD_{0.5}$*	2.97	3.15	1.85	3.66

1 Aggregation index = (A–B)/A X100, where A and B are silt plus clay of a completely dispersed and not dispersed sample, respectively.

*Significant at 0.05 level.

Table 2. Water absorption capacity ml/gm of Culture Plus at different water quality.[1]

Water quality	Maximum absorption capability ml/gm
Distilled water	333.37
EC 1 dS/m	135.83
EC 2 dS/m	88.07
EC 4 dS/m	49.17
$LSD_{0.05}$*	2.92

1 Culture Plus of 0.02 gm was added to 100 ml of different water quality.

*Significant at 0.05 level.

Table 3. Cumulative evaporation of soil columns as affected by "Culture Plus" concentration and water quality.

Culture Plus rates	Cumulative evaporation (mm) cycle		
	1	2	3
	Distilled water		
Control	18.80	38.33	59.98
0.2%	17.70	32.30	50.37
0.4%	14.66	29.86	47.16
0.6%	16.88	32.86	51.85
$LSD_{0.05}$*	0.75	0.85	1.45
	Electrical conductivity 1 (dSm^{-1})		
Control	18.50	37.99	59.16
0.2%	17.56	36.17	56.26
0.4%	14.53	31.36	48.84
0.6%	17.23	32.84	50.74
$LSD_{0.05}$	0.93	1.25	2.24
	Electrical conductivity 2 (dSm^{-1})		
Control	18.12	35.93	54.92
0.2%	17.20	33.93	52.86
0.4%	14.92	30.02	46.55
0.6%	17.31	35.35	56.36
$LSD_{0.05}$	1.08	1.47	2.33
	Electrical conductivity 4 (dSm^{-1})		
Control	18.71	37.99	58.22
0.2%	16.46	34.33	53.37
0.4%	14.48	28.94	45.87
0.6%	14.51	30.31	48.91
$LSD_{0.05}$	1.30	2.02	3.34

*Significant at 0.05 level.

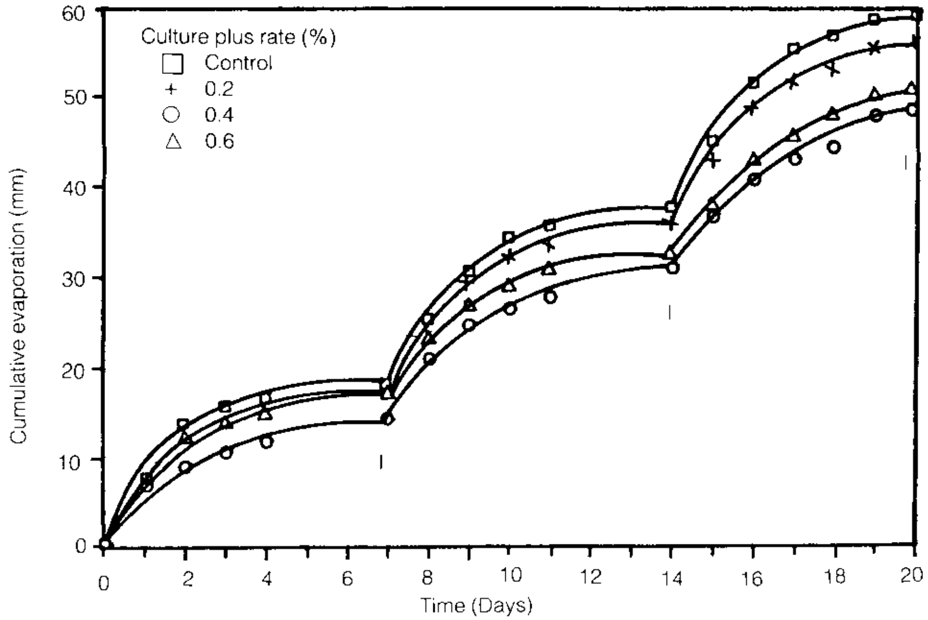

Fig. 1. Cumulative evaporation from soil columns as affected by Culture Plus rate at EC of 1 dS m^{-1}.

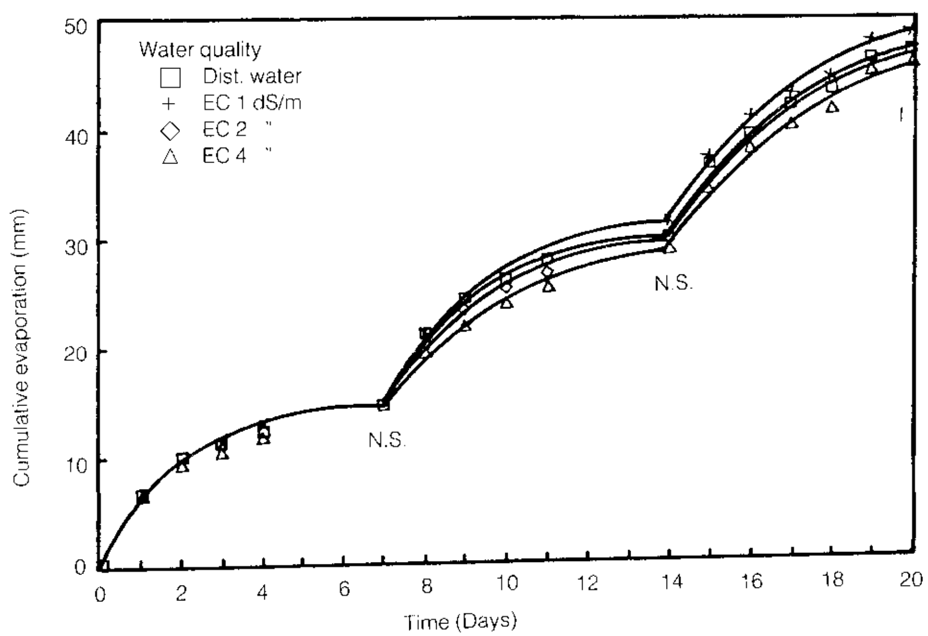

Fig. 2. Cumulative evaporation from soil columns as affected by water quality at Culture Plus rate of 0.4%.

Table 4. The percentage of water conserved[1] in soil columns as affected by "Culture Plus" concentration and water quality.

Culture Plus rates	Water conserved (%) cycle		
	1	2	3
	Distilled water		
Control	14.56	12.88	9.33
0.2%	19.48	26.59	23.68
0.4%	33.34	32.13	28.54
0.6%	23.27	25.31	21.44
$LSD_{0.05}$*	3.37	1.95	2.20
	Electrical conductivity 1 (dSm^{-1})		
Control	15.91	13.91	10.63
0.2%	20.16	17.79	14.75
0.4%	33.97	28.73	26.00
0.6%	21.67	25.37	23.11
$LSD_{0.05}$	4.26	2.77	3.10
	Electrical conductivity 2 (dSm^{-1})		
Control	17.65	18.35	16.78
0.2%	21.79	22.89	19.91
0.4%	32.18	31.78	29.47
0.6%	21.33	19.67	14.61
$LSD_{0.05}$	4.91	3.35	3.53
	Electrical conductivity 4 (dSm^{-1})		
Control	14.95	13.65	11.78
0.2%	25.17	21.97	19.13
0.4%	34.17	34.22	30.51
0.6%	34.06	31.10	25.89
$LSD_{0.05}$	5.90	4.59	5.02

1) Percentage of water conserved is the amount of water conserved divided by cumulative quantity of water applied and multiplied by 100.

*Significant at 0.05 level.

The effect of the conditioner rate and water quality on infiltration is shown in Table 5. Infiltration was affected by the rates of the conditioner and water quality. For distilled water, infiltration decreased with addition of gel-conditioner. The third cycle required more time to infiltrate as compared to first or second cycles with the exception of $C_{0.4}$. During the third cycle at distilled water the infiltration time ranked as follows: $C_{0.0} > C_{0.6}\ C_{0.2} > C_{0.4}$. For the water quality of EC 1, 2, and 4 dS m^{-1}, all the treatments gave lower infiltration time than the control of the distilled water at each cycle. At water quality of EC 1 and 2 dS m^{-1}, $C_{0.6}$ a higher significant infiltration time than other treatments – including the control – was given. Whereas, EC of 4 dS m^{-1}, $C_{0.6}$ gave lower time than the $C_{0.0}$ and $C_{0.2}$ in the three cycles.

Figure 3 shows the soil moisture content at the end of the experiment for different conditioner rates and water qualities. For the conditioner rates, the soil moisture profiles showed that the higher the conditioner rate, the higher the moisture content. The soil moisture profiles of $C_{0.0}$ and $C_{0.2}$ at EC of 2 dS m^{-1} showed a drying zone at the surface, a transmission zone in the middle, and a dry zone at the end. However, at $C_{0.4}$ and $C_{0.6}$, the moisture content was higher at the surface and gradually decreased with depth of the soil columns. The moisture content profile for the different water quality showed a drying zone at the surface, a transmission zone in the middle, and a dry zone at the bottom. Also Fig. 3 shows that there was no difference between distilled water, EC 1, EC 2, and EC 4 dS m^{-1}. Conditioning sandy soil with a high rate of Culture Plus gel-conditioner increased its water content.

Figure 4 shows the EC profiles at the end of the experiment. For the conditioner rates the EC profile showed a higher EC at the top and then decreased with depth. At the surface the EC of the treatment was in the following order: $C_{0.6} > C_{0.4} > C_{0.2} > C_{0.0}$, whereas at the 0.25 m depth the EC ranked as follows $C_{0.2} > C_{0.4} > C_{0.0} > C_{0.6}$. The EC profiles at different water quality showed a high EC at the top then decreased with depth the exception of the distilled water. For the distilled water the EC was low at the top and increased with depth. The variation of water content and EC of soil profiles depend on the rate of conditioner and the water quality used for irrigation.

Discussion and Conclusions

Decreased water absorption capacity of the conditioner with different water quality is a result of increased salt concentration in the water. The improved aggregation of conditioned soils might be attributed to the properties of the gel-forming conditioners which acts as a cementing agent in the soils. However, the increase of aggregation index of conditioned soils with salt solution is due to flocculation effect. Helalia and Letey [14] reported that the rate of 5 mg L^{-1} of polyaccrylamide (PAM) increased the flocculation of the soils. They found that the increase was higher with higher salt concentration in irrigation water (well water).

Table 5. Time required to infiltrate 22 mm into the soil columns as affected by soil conditioner and water quality.

Culture Plus rates	Time (seconds) cycle 1	2	3
	Distilled water		
Control	58.33	81.33	97.33
0.2%	26.00	24.67	23.67
0.4%	29.67	14.67	17.33
0.6%	47.67	33.00	36.00
$LSD_{0.05}$*	7.29	13.38	8.63
	Electrical conductivity 1 (dSm^{-1})		
Control	28.00	32.33	30.00
0.2%	19.00	17.63	20.00
0.4%	13.33	13.00	15.67
0.6%	42.33	30.00	30.33
$LSD_{0.05}$	5.38	4.68	3.95
	Electrical conductivity 2 (dSm^{-1})		
Control	26.67	28.67	30.33
0.2%	18.67	22.00	21.00
0.4%	17.00	13.33	19.33
0.6%	41.67	41.33	43.67
$LSD_{0.05}$	4.37	2.66	2.66
	Electrical conductivity 4 (dSm^{-1})		
Control	18.71	37.99	58.22
0.2%	16.46	34.33	53.37
0.4%	14.48	28.94	45.87
0.6%	14.51	30.31	48.91
$LSD_{0.05}$	1.30	2.02	3.34

*Significant at 0.05 level.

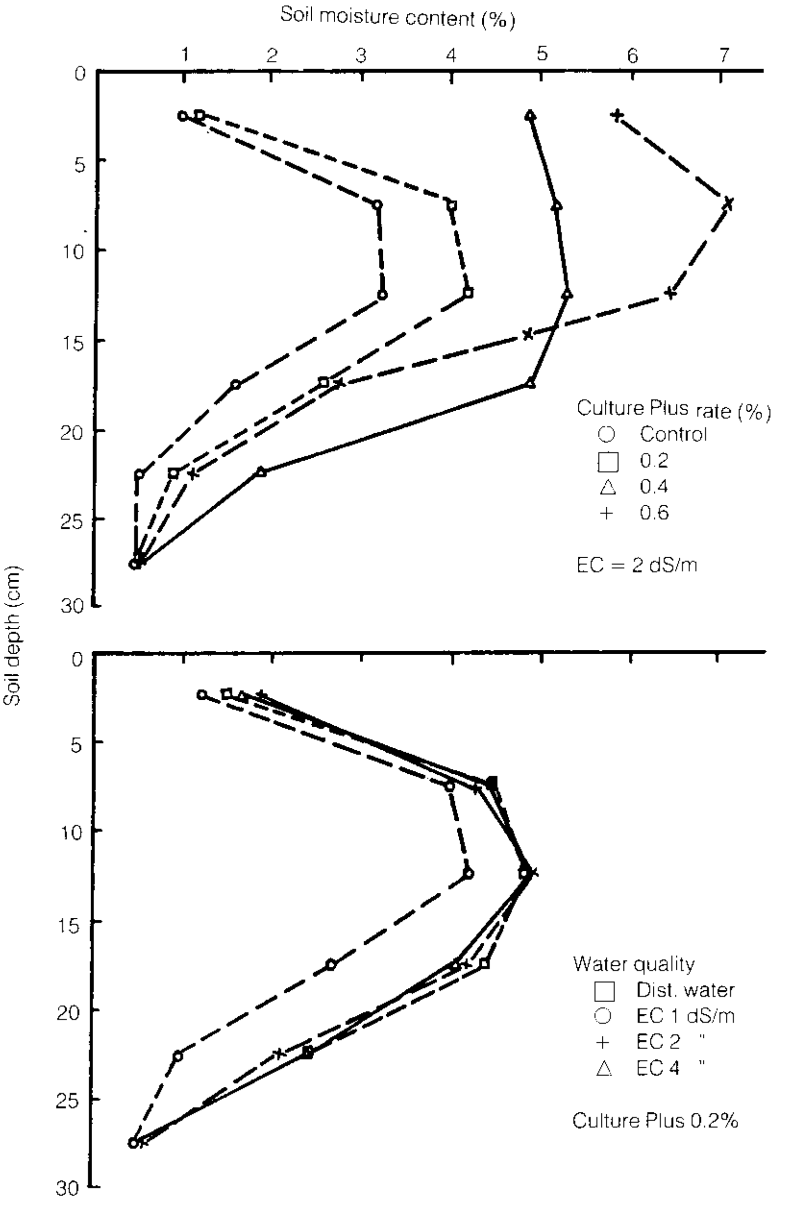

Fig. 3. Soil moisture profile at the end of the third cycle as affected by Culture Plus rate at EC = 2 dS m^{-1} (upper) and as affected by water quality at Culture Plus of 0.2% (lower).

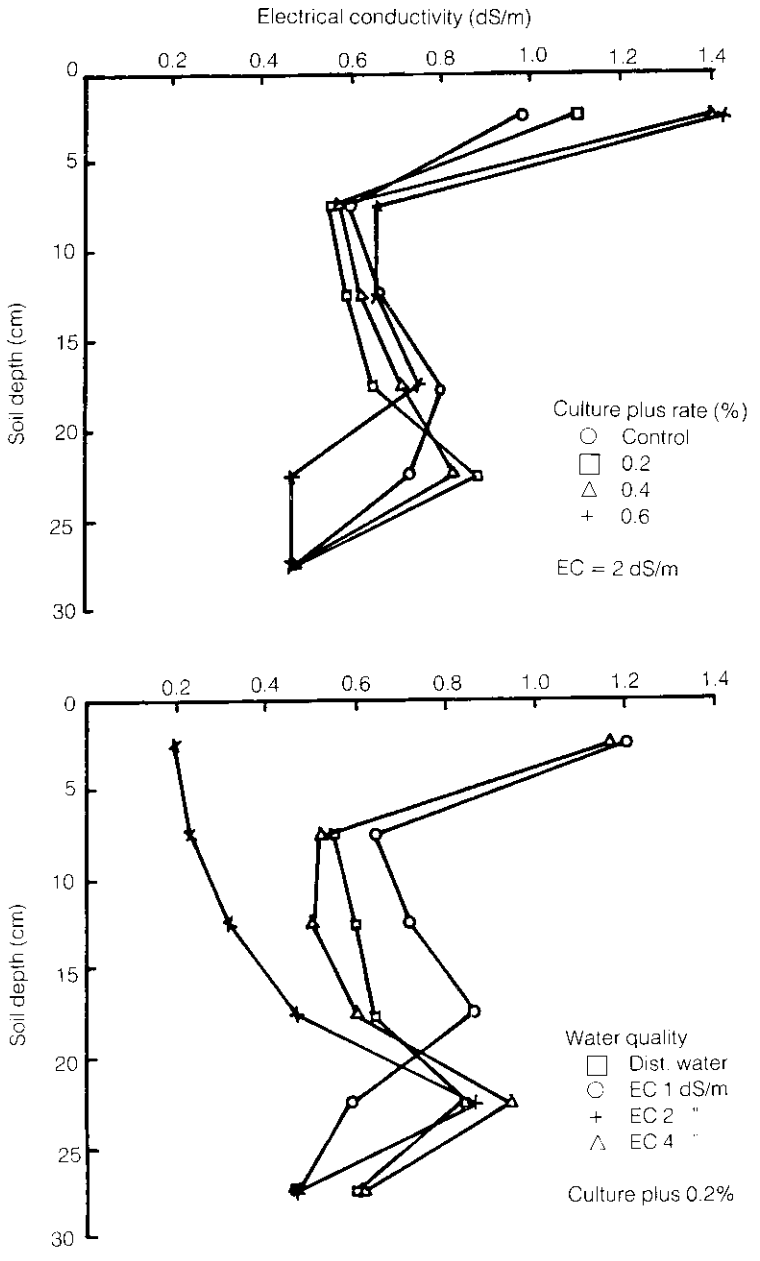

Fig. 4. Electrical conductivity (1:1 dS m^{-1}) at the end of the third cycle as affected by Culture Plus rate at EC = 2 dS m^{-1} (upper) and as affected by water quality at Culture Plus rate of 0.2% (lower).

The influence of Culture Plus conditioner rate on evaporation may be due to its effect on aggregation and swelling as reported in previous work [3]. The result showed that the $C_{0.4}$ has lower cumulative evaporation, which indicated that the Culture Plus caused an aggregation effect. Thus, it promoted the infiltration rate, limited capillary rise and suppressed evaporation. The results showed that the higher rate of Culture Plus $C_{0.6}$ increased the cumulative evaporation which might be attributed to the swelling effect.

The reduction in cumulative evaporation with high salt water is mainly due to aggregation effect which resulted in high infiltration rate to the bottom of the column and consequently suppressed evaporation. For the water quality treatment at the same rate of Culture Plus, the nonsignificant effect of the gel-forming conditioner on the cumulative evaporation may be due to the nature of the gel conditioner itself when salt solution is added to it. This was suggested by the result of the water absorption capacity of the conditioner at different water quality.

It can be concluded that the beneficial effect of Culture Plus at a rate of 0.4% or lower was to reduce the cumulative evaporation by increasing aggregation effect which enhanced infiltration. The use of saline water will reduce the absorption capacity of the gel conditioner. While this decreases the beneficial use of gel conditioner, the use of such conditioner should be restricted to water with low salt concentration.

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تأثير نوعية المياه ومعدل المحسن الصناعي على البخر المتقطع

عبدرب الرسول موسى العمران وعادل أبو شعيشع شلبي

قسم علوم التربة، كلية الزراعة، جامعة الملك سعود

الرياض المملكة العربية السعودية

ملخص البحث. درس التأثير المشترك لكل من المحسن الصناعي المسمى تجاريًا Culture Plus ونوعية من المياه ذات قيم مختلفة من التوصيل الكهربي على التحبب والبخر المتقطع للتربة الرملية.

كانت المياه تضاف في التجربة مرة كل سبعة أيام بمقدار ٢٢مم لكل عمود ولمدة ثلاثة أسابيع.

أظهرت النتائج أن معامل التحبب زاد معنويًا بمقدار ٢,٢٤ ، ١٠,٨٦ و ١٧,٠٦ نتيجة لإضافة ٠,٢ ، ٠,٤ و ٠,٦٪ من Culture Plus على التوالي - بينما زاد الماء الميسر بمقدار ٥١ ، ٧٣ و ١٢٢٪ عند معدلات الإضافة نفسها للمحسن.

كذلك أظهرت النتائج أن السعة الامتصاصية للماء لهذا المحسن نقصت معنويًا بمقدار ٥٩,٣ ، ٧٣,٦ و ٨٥,٥٪ مع زيادة التوصيل الكهربي للماء إلى ١ ، ٢ و ٤ سيمند/متر على التوالي، وقد وجد أن المعدل ٠,٤٪ من Culture Plus سبب انخفاضًا معنويًا في البخر - مقارنًا بالمعاملات الأخرى - وذلك عند استخدام المياه المختلفة النوعية. وقد أدى ذلك إلى زيادة الاحتفاظ بالماء. كذلك أظهرت النتائج عدم وجود اختلاف معنوي في الدورة الأولى بين نوعية المياه عند المعدل المميز Culture Plus .