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Effect of Irrigation Water Type on Infiltration Rates of Sandy Soils

تأثير نوعية المياه على معدل التسرب في الترب الرملية

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Abstract: A laboratory experiment was conducted to test the effect of three water types (tap water, well water and sewage water) on the infiltration rate of three soils varying in texture (sand, loamy sand and sandy clay loam). A stationary rainfall simulator dispensing water at a rate of 45mm h-1, connected to the different sources of water, was used to measure the infiltration rates. A total of 5 runs were carried out using each water quality. The volume of runoff against the time was recorded at each 5 minute interval. The infiltration rate was calculated as the difference between the water applied and the excesses water measured as surface runoff. Infiltration rates at the first run were rapid in all the three soils and then progressively declined as the number of runs increased. The same trend was observed for each water quality tested. The reduction in infiltration rate with increasing number of runs for prewetted surface than for the initial dry surface was attributed to the break down and settling of fine particles that took place earlier during prewetting. The infiltration curves for all the three soils when irrigared with different qualities of water was not distinguisable. The relationship between infiltration rate as a function of time for the treatments applied were tested using Kostiakov equation I = Bt-n. The infiltration data gave a coefficient of determination R2 > 0.90 for all the treatments. The infiltration parameters B, and n varied strongly with respect to soil texture. Values of B decreased with changing soil textures, being heighest for the sandy soil and lowest for the sandy clay loam soil, whereas n values showed the opposite trend. It was concluded that the effect of soil texture on infiltration rate was very pronounced while water qualities showed a little effect.

Keywords: Infiltration, water quality, sewage water, soil texture

المستخلص: صممت تجربة في المعمل لمعرفة تأثير ثلاثة أنواع من المياه (ماء الصنبور، وماء بئر، ومياه الصرف الصحي المعالجة) على معدل التسرب المائي لثلاثة أنواع من الترب تختلف في قوامها. صمم جهاز محاكاة المطر وبمعدل 45ملم/ ساعة متصلة بخزانات المياه المستخدمة في التجربة. لقد تم استخدام خمس محاولات لقياس التسرب المائي لكل نوعية من الماء مع كل تربة. تم قياس حجم الماء الجاري من سطح التربة كل خمس دقائق ومنها تم حساب معدل التسرب، وهو الفرق بين معدل الإضافة والجريان من سطح التربة. كان معدل التسرب المائي في المحاولة الأولى سريعاً لجميع الترب المستخدمة في التجربة، وبزيادة المحاولات انخفض معدل التسرب. ويرجع السبب في ذلك لترطيب سطح التربة مقارنة بالتربة الجافة في المحاولة الأولى. لم يظهر أثر واضح ومعنوي لتأثير نوعية المياه على معدل التسرب في التجربة. لقد استخدمت معادلة كوستكوف لتوضح العلاقة بين معدل التسرب و الزمن وأعطت قيم لمعامل التحديد أكثر من 0.90 لجميع المعاملات في التجربة. القيم الثابتة في المعادلة (n , B) اختلفت مع اختلاف قوام التربة حيث كانت قيم (B) أعلى في الترب الرملية وأقل في الترب الطميية الطينية الرملية بينما قيم (n) كانت أقل في الترب الرملية. ويتضح من التجربة أن تأثير قوام التربة كان واضح ومعنوياً على معدل التسرب المائي في الترب بينما نوعية المياه المستخدمة لم تظهر هذا التأثير.

كلمات مدخلية: مياه، معدل التسرب، تربة رملية، معادلة كوستكوف

Introduction

The ecosystem of the desert of Saudi Arabia is impoverished by scarcity of water resources. With the increasing needs of water mainly for agriculture use, irrigated agriculture faces the need to use poorer water quality. In Saudi Arabia as in many arid countries the use of treated sewage water has become a necessity to overcome the shortage of water in agriculture. In Riyadh, the amount of tertiary-treated sewage water is estimated to be 420,000 m^3/month in 2000 (KSA, 2003). The utilization of treated sewage water is rapidly increasing in both the agricultural and the industrial sectors in many regions of Saudi Arabia. The intensive use of such water for irrigation soils need to be investigated for better management optimization of water resources and irrigation systems.

Infiltration rate of soils is one of the most important factors in designing a suitable irrigation system using poor quality water. In arid areas water conservation is a necessity and determining infiltration rate is a must for an irrigation system to avoid surface runoff. Many studies have documented the effect of water quality on infiltration rate under laboratory and field conditions. Oster and Schroer (1979) showed that the pounded infiltration rate into undisturbed soil columns was controlled by the chemical properties of infiltration water through its effects on the soil surface rather than by the chemical properties of the soil. Agassi *et al.* (1981) attributed the decrease in infiltration rate of simulated rain to greater soil surface dispersion where EC of the water applied decreased as soil exchangeable Na percentage increased. In another study, Baumhardt *et al.* (1992) reported that the infiltration rate and amount of water infiltrated increased when soil salinity and sodicity decreased or the salinity of the applied water increased. Wienhold and Trooien (1995) showed that 10 years of irrigation changed the EC and SAR in the 0 to 0.15 m depth of soil. In another study Wienhold and Trooien (1998) reported that the reduction of infiltration rate related to the increase in the soil SAR and they suggested that soil physical deterioration was apparent at SARs much lower than the SAR 13 commonly used to describe a soil as sodic.

The effect of treated sewage water (TSW) on soil infiltration varies with soil type and sewage water characteristics. Irrigation TSW may change soil physical properties (Mathon, 1994), chemical properties (Feigin, *et al.* 1991), or biological (Schipper *et al.*, 1996). Many studies have shown decrease in hydraulic conductivity with the application of sewage water to soil (Thomas, *et al.* 1966; Lance *et al.*, 1980; Clanton and Slack, 1987; Balks, *et al.* 1997). Keren (1991) showed that the adsorbed Mg by the soil decreased infiltration rates regardless of CaCO3 content in the presence of sodium. Clanton and Slack reported that the hydraulic conductivity decreased during the application of treated wastewater to soils. Vinten, *et al.* (1983) suggested that the reduction in hydraulic conductivity was attributed to the chemical, physical and biological process, and the physical process was more important in clogging the soil by the suspended solids. Abo-Ghobar (1993) reported, in his study in Saudi Arabia, that reduction in infiltration rate was greatest for the soil under the application of treated wastewater due to the effect of accumulation of solids at the soil surface. Magesan *et al.* (1999) reported that using secondary-treated wastewater and tertiary-treated water in irrigation of a sandy soil had no significant effect on unsaturated hydraulic conductivity. However, for the same soil and treatment, Cook, *et al.* (1994) reported a 50% decline in infiltration rates. Mathon (1994) reported an increase in hydraulic conductivity after application of municipal treated wastewater and attributed this increase to change in soil physical properties.

The objective of this study is to compare the effect of different types of irrigation water (tap water, well water and treated sewage water) on the infiltration rate of three soils varying in texture (sand, loamy sand and sandy clay loam).

Materials and Methods

The experiment was conducted in an irrigation laboratory at the Agricultural Experimental Station of King Saud University, Riyadh. A stationary spray system (rainfall simulator) attached to a water tank, attached to three types water (tap water, well water and sewage treated water), was constructed to measure the infiltration. The detailed set up of the experiment is given in diagram 1. The tank has a capicity of $4M^3$ with a pump attached to give an operating pressure of 10^3 kpa during the runs. Three cylindrical metal boxes of 22.5 cm diameter and 40 cm depth were used for the soils. Many small holes were drilled into the bottom of each tank to allow the infiltrated water to drain into another tank (Fig.1).

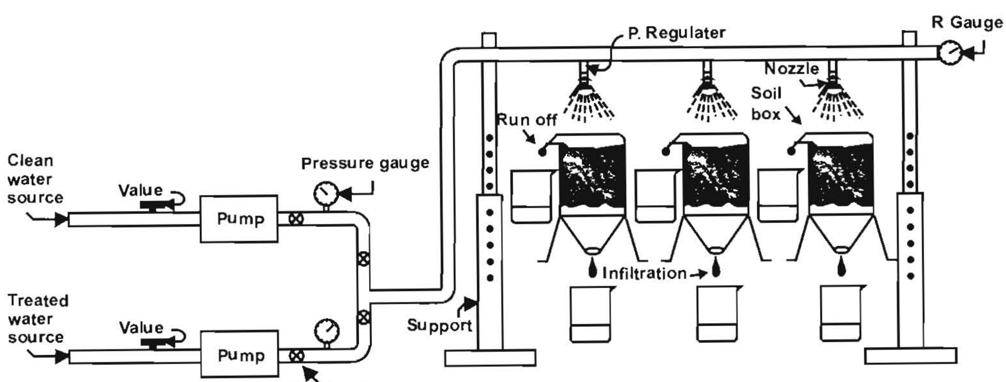


Figure 1. A schematic diagram of a stationary rainfall simulator used for irrigation of soils.

Preliminary tests were conducted with each nozzle to select a suitable nozzle height and space adjusted in such a way that each soil box will receive water exactly at a rate of 45mm hr^{-1}.

Three bulk surface (0-30cm) soils varying in texture (sand, loamy sand and sandy clay loam) were collected from College Experimental Station at Dirab, 40km south west of Riyadh. The soils were air dried crushed, and passed a through 2mm sieve before packing. The boxes were filled with soil and compacted using a wooden brick in such a way that the bulk density of the packed soil was approximately close to 1450Kg m^{-3}. Soils and waters samples were analyzed using the recommended methods described by Richards (1954) and the results are presented in table 1 & 2.

Table 1. Physiochemical characteristics of soils used in this study.

Characteristics	Soil 1	Soil 2	Soil 3
ECe (dS m^{-1})	1.4	1.9	5.9
SAR	2.34	1.71	4.31
SAR_{adj}	4.59	3.45	8.45
pH	7.44	7.38	7.44
K	8.7	3.8	1.7
S.P. (%)	30.3	31.3	29.6
O.M. (%)	0.1	0.1	0.1
$CaCO_3$ (%)	24.9	26.2	31.9
<u>Cations (meq / l)</u>			
Ca^{++}	5.15	11.0	26.3
Mg^{++}	2.9	4.0	12.2
Na^{+}	3.2	4.7	18.9
K^{+}	1.0	2.0	3.6
<u>Anions (meq / l)</u>			
$CO_3^{=}$	0.1	2.8	0.5
HCO_3^{-}	3.0	5.0	8.0
Cl^{-}	4.0	6.0	21.0
$SO_4^{=}$	5.6	7.8	30.6
Sand (%)	91.0	80.0	60.0
Silt (%)	8.0	15.0	18.0
Clay (%)	1.0	5.0	22.0
Textural class	Sand	Loamy sand	Sandy clay loam

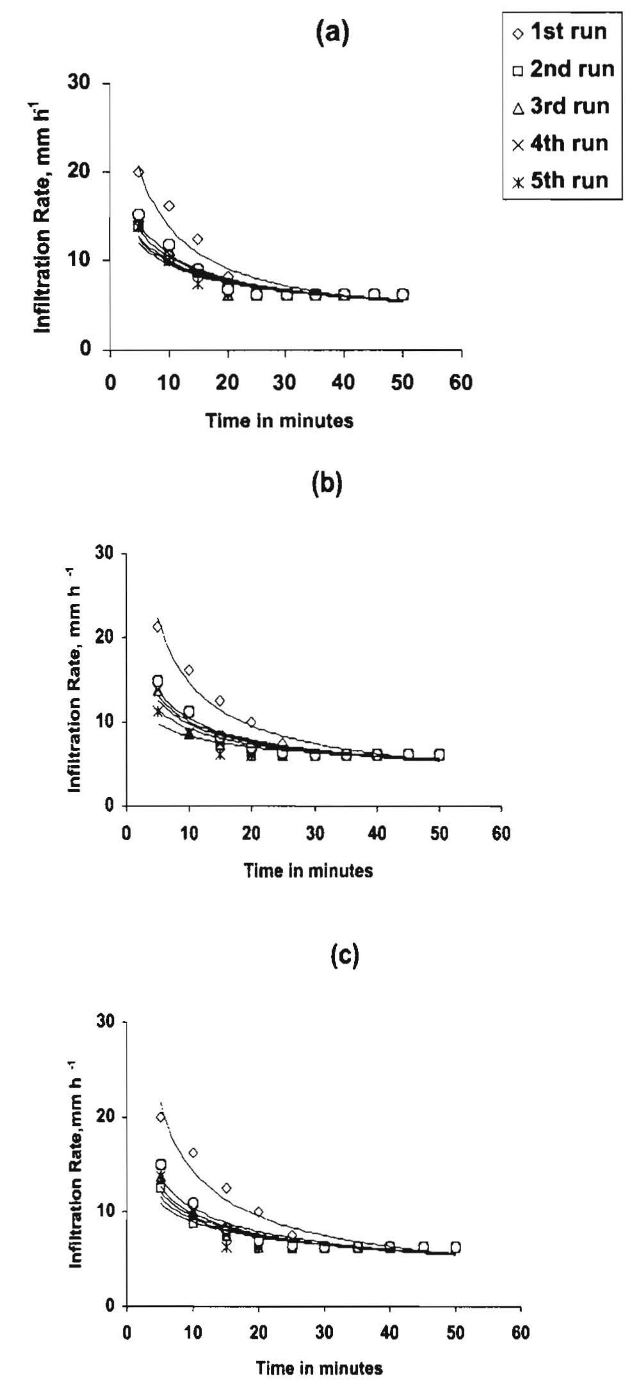
Table 2. Chemical composition of three water used in the experiment.

Characteristics	Tap water	Well water	Treated sewage water
EC_w (dS m^{-1})	0.4	4.7	1.7
pH	7.0	7.50	6.94
TSS (mg L^{-1})	Nil	Nil	180
SAR	1.19	5.16	4.1
SAR_{adj}	2.85	9.8	10.09
<u>Cations (meq/l)</u>			
Ca^{++}	2.1	15.8	4.7
Mg^{+}	0.3	11.0	3.1
Na^{+}	1.3	18.9	8.1
K^{+}	0.34	0.54	0.7
<u>Anions (meq/l)</u>			
$CO_3^{=}$	Nil	Nil	Nil
HCO_3^{-}	0.9	3.75	1.25
Cl^{-}	1.4	14.6	8.0
$SO_4^{=}$	1.7	27.9	6.4

The first run of infiltration was done on dry soil, while the average water content in the soil for the other runs was nearly constant and ranged from 8 - 12% depending on the texture of the soil. A total of 5 runs were caried for each water type and each box was used as a replicate. The soils of the boxes were changed and filled similarly as above and infiltration was run for each water type. The volume of runoff against the time was recorded at 5 minutes intervals for each treatment. The infiltration rate was calculated as the difference between the water application rate and measured runoff.

Results and Discussion

The effect of water type on the infiltrations through three soils varying in their textures is shown in Figs. 2 & 3. Infiltration rates at the first run were very rapid in all the three soils and then progressively declined as the number of runs increased (Fig. 3). The same trend was observed for each water type tested using sandy clay loam (Fig. 2). This reduction with increasing numbers of runs is mainly attributed to soil moisture condition. Infiltration rates were less for prewetted surfaces than for the dry surface due to development of the surface seal caused by the breakdown and settling of fine particles that occurred earlier during



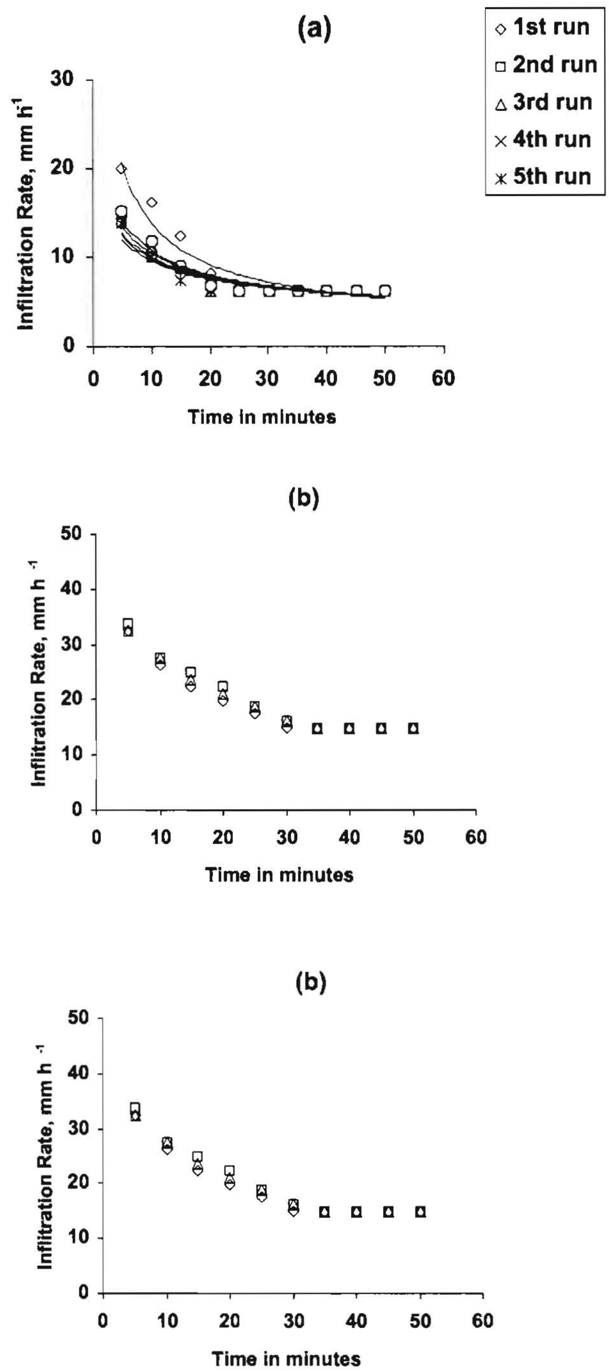


Fig . 2. Effect of water quality on soil infiltration under sandy clay loam soil through 5 runs for:
(a)tap water
(b)well water and
(c) treated sewage water

Fig. 3. Effect of water quality on infiltration rate under different soil texture for:
(a) Sandy soil
(b) Loam sandy and
(c)Sandy clay loam soil.

prewetting. Similar results were obtained by Morin and Benyamini, 1977 and Levy, *et al.* 1994. The effect of water quality on infiltration at a given soil texture is plotted in Fig. 3. The difference in infiltration curves for different water quality were not easily distinguishable. The data indicated no significant reduction in infiltration rate using treated sewage water when compared to well water. The slight reduction observed in infiltration rate in sandy clay soil using sewage treated water may be due to the clogging of soil particle pores by suspended solids which restricts water movement, and thus decrease infiltration rate (Abo-Ghobar, 1993). The data in Fig.3 indicated that infiltration rate under well water application resulted in a slight increase in infiltration compared to sewage water. This increase may be due to high salt contents of well water that resulted reduced dispersion at the soil surface when applied to the soils. Similar results were reported by Oster and Schroer, 1979; Baumhardt, *et al.* 1992 and Kim and Miller, 1996. The application of treated sewage water to soil tends to increase the accumulation of suspended solids in the soil surface, which resulted in lower infiltration rate. This finding is in agreement with the results reported by Clanton and Slack (1987). The degree of clogging pores in soils depends upon the concentration of suspended solids in the water (Mageson *et al.*, 1999), through its effect a soil surface condition and chemical and physical properties of soils.

The relationships between infiltration rate for different treatments as a function of time were demonstrated by fitting the data in the Kostiakov (1932) equation

$$I = Bt\text{-}n$$

where I is the infiltration rate in mm hr^{-1} and B and n are infiltration parameters that depend on soil properties and initial soil conditions. The infiltration data when fitted in the above equation gave coeffecient of determination (R2) values greater than 0.90 in all the treatments (Table 3). Nevertheless, the infiltration parameters (B and n) varied strongly with respect to textural differences. The B values for all the water qualities decreased with changing soil texture, highest for the sandy soil and lowest for sandy clay soil. However n values showed the opposite trend, that increased with changing soil texture and were the lowest in sandy soil and the highest in sandy clay soil. The decrease in values of B parameter were consistent with each water quality and were the highest for well water, followed by treated sewage water and than tap water. This may be attributed to the high electrolytes concentration of well water (ECw = 4.7 dSm^{-1}) that resulted in flocculation of fine soil particles particularly higher in sandy clay loam soil (Kim and Miller 1996). Effect of soil texture on infiltration as a function of time is further demonstrated very clearly in Fig. 4. Water movement into the soil was rapid for the first 15-20 minutes and than declined steadily irrespective of water quality and infiltration rates were in the order of sandy < loam sandy > sandy clay loam.

Table 3. The Infiltration parameters β, n and coefficient of determination (R^2) computed by using Kostiakov equation.

Water Quality	Soil Texture	R^2	β	n
Tap Water	Sandy	0.95	73.50	0.29
	Loamy Sand	0.97	61.20	0.38
	Sandy clay Loam	0.90	53.60	0.59
Well Water	Sandy	0.93	77.60	0.29
	Loamy Sand	0.96	69.30	0.40
	Sandy clay Loam	0.94	59.70	0.61
Treated Sewage Water	Sandy	0.96	75.01	0.28
	Loamy Sand	0.97	64.60	0.39
	Sandy clay Loam	0.94	55.70	0.67

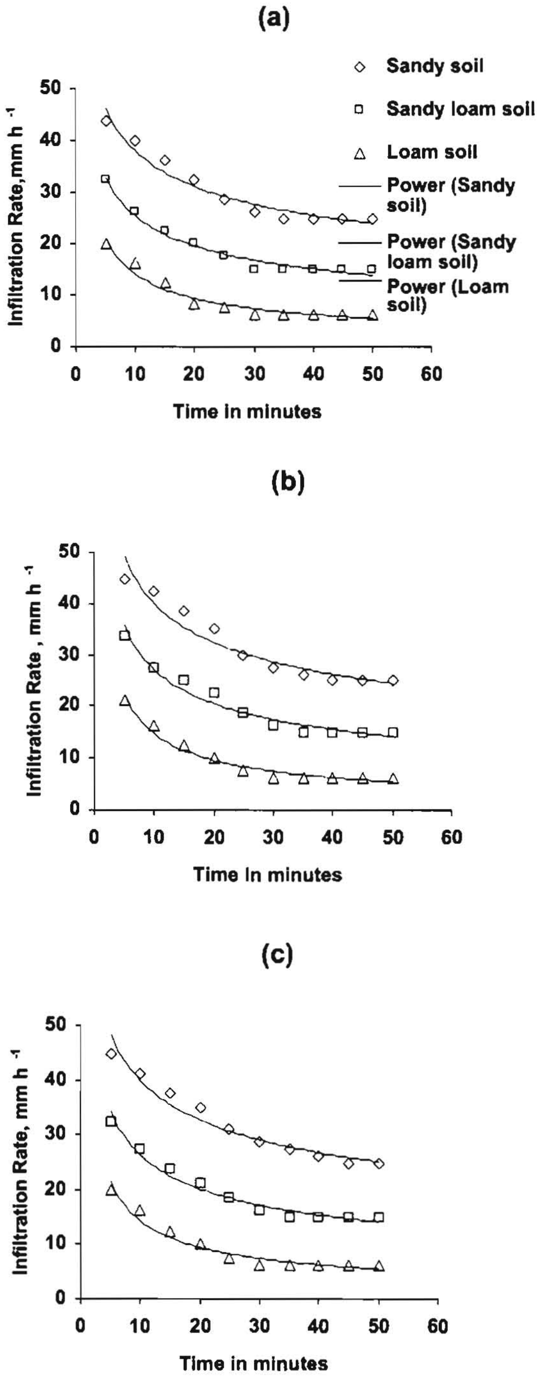


Fig. 4. Effect of soil texture on soil infiltration under
(a) Tap water
(b)Well water and
(c) Treated sewege water

Conclusions

The results obtained showed that soil texture has a pronounced effect on filtration rate, highest in sandy soil and lowest in sandy clay loam. Initally in all the three soils, when dry, infiltration was rapid and than steadily decreased with time whereas, infiltration rates were slightly affected by water type.

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