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Water Infiltration and Permeability of Selected Urban Soils as Affected by Salinity and Sodicity

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Summary

Soil sodicity is known to affect soil structural stability and permeability. However, the impact differs depending on salinity of irrigation water, soil types as well as irrigation management practices. This study examined water infiltration into two alluvial soils (Torrifluvents), and two upland soils (Paleorthid and Calciorthid, Aridisols) placed in greenhouse pots. For the first experiment, irrigation solutions simulating the Rio Grande water, city potable water, and two sources of reclaimed water (EC of 1.4 and 2.2 dS m^{-1} and SAR of 6 and 11) were applied twice a week at 1.7 cm per application for a total of 27 irrigation events using 46 cm of water. No significant effect of water quality was detected in Delnorte gravelly loam (Paleorthid) and a small effect on infiltration into Harkey silt loam (Torrifluvent). However, the use of distilled water curtailed infiltration mainly in Harkey soil. In the second greenhouse experiment using a carefully crafted soil packing and water application protocols, the impact of water quality on infiltration into two Torrifluvents, Harkey silt loam and Glendale silty clay loam appeared after water application of 40 to 50 cm (16" – 20"). When saline solutions were applied as deep as 10 cm per application, the infiltration time nearly doubled when SAR of the solution increased from 1 to 6 or 12 in alluvial soils, but not in Turney silty clay loam (Calciorthid, Aridisol). When the irrigation depth per application was reduced to 7.5, 5.0, and 2.5 cm per application, the difference in infiltration rate was markedly reduced. The impact of elevated sodicity (SAR of 6 to 12) on infiltration can be an issue in alluvial soils, but unlikely in upland soils at irrigation water salinity of 1 to 2 dS m^{-1}.

Introduction

There is no shortage of literature which warns the impact of sodicity on soil structure and water infiltration. The US Golf Association (USGA), for example, recommends not to use water with the sodium adsorption ratio (SAR) greater that 6 for irrigating golf courses except under special circumstances (USGA, 1994). The California guidelines (e. q., Westcot and Ayers, 1984) indicate that the permissible level of water sodicity should be adjusted to salinity of irrigation water. The majority of soil and water testing laboratories indicate that the SAR exceeding a range of 6 to 8 can adversely affect soil structure and water infiltration. Research conducted in California has shown that a significant reduction in hydraulic conductivity depends on soil type, and occurred at salinity of the water below 1.2 dS m^{-1} at the exchangeable Na percentage (ESP) of 20 (McNeal and Coleman, 1966). Another study, also performed in California, indicates that Na ions can encourage aggregate slaking, mostly at salinity below 1 dS m^{-1}, but may extend to 1.5 dS m^{-1} when SAR increases to 10 in some soils (Abu-Sharar et al., 1987a, 1987b). Research conducted in Israel indicates that clay swelling is a slow process, and may occur only if soil salinity is below 1.2 dS m^{-1} in montmorillonite (Keren and Singer, 1988). Frenkel et al. (1978) found that a significant reduction in hydraulic conductivity of sandy soils can occur at ESP as low as 5 when salinity of water is less than 1 dS m^{-1}, due to clay particle dispersion. The same finding was later reported by

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Alperovitch et al. (1985) in artificially prepared soil materials: 95% of fine to medium sand (0.1 to 0.6 mm) containing 5% montmorillonite.

Since the flocculation value (which causes flocculation of clay particles) is reported to depend on types of clay present, we have to assume that the soil response to water quality would also depend upon soil types. Likewise, water infiltration response to water quality is likely to be soil-dependant, as the forms of aggregates differ among the soils. Upland soils in the Southwest are, for example, often cemented with calcium carbonate, and their aggregates are less likely to be affected by Na. The following experiments were performed for evaluating the effect of salinity and sodicity on water infiltration and permeability of selected urban soils in El Paso, Texas.

Methods and Results

Experiment 1. Infiltration of Shallowly Applied Water: The primary objective of this experiment was to observe the time required for 1.7 cm (5/8”) of water to infiltrate into three soils; Harkey silt loam (Typic Torrifluvent, Entisol), Delnorte gravelly loam (Typic Paleorthid, Aridisol), and the A-horizon of Hueco sandy loam (Petrocalcic Paleargid). These soils were passed through a 4 mm screen, and placed in six-inch plastic pots. The surface of the potted soil was concaved so as to accept water application up to 1.7 cm. The potted soil was placed in a greenhouse, and was irrigated twice a week at 1.7 cm (0.67 inches) which is the daily equivalent rate of 0.49 cm, a typical evaporation rate from common Bermudagrass turf in west Texas. During the 10th, 16th and 27th irrigation, only the distilled water was used in all cases. The time required for the 1.7 cm of water to infiltrate was measured for a total of 27 irrigation events over the 13 week period.

Results are shown in Fig. 1 for Harkey silt loam and Delnorte gravelly loam. Results from Hueco sandy loam were similar to those of Delnorte gravelly loam, thus are not shown for simplicity. The time required for infiltration of various solutions was similar, except when the distilled water was applied following the application of city potable water in Harkey silt loam. Based on these observations, we concluded that the effect of reclaimed water in infiltration of shallow depth of water is not of a serious concern when compared against city potable water or the project water from the Rio Grande at least in a short term.

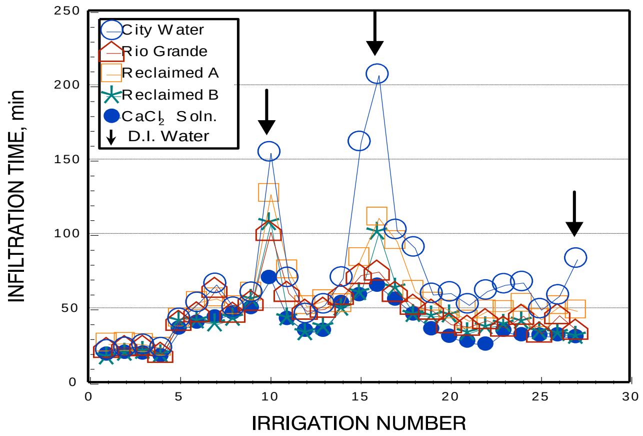
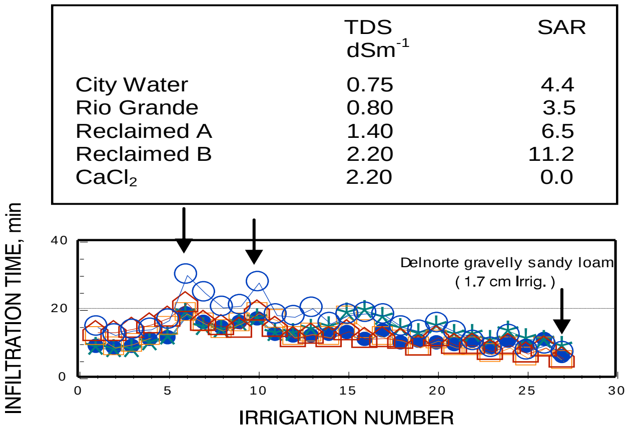


Fig. 1A. The time required for 1.7 cm of specified solutions to infiltrate into Harkey loam, Entisol.



	TDS dSm^{-1}	SAR
City Water	0.75	4.4
Rio Grande	0.80	3.5
Reclaimed A	1.40	6.5
Reclaimed B	2.20	11.2
$CaCl_2$	2.20	0.0

Fig. 1B. The time required for 1.7 cm of specified solutions to infiltrate into Delnorte gravelly loam, Ardisol.

In conjunction with this infiltration test, we prepared extra pots of soils which were to be leached with distilled water using 12 cm in depth after the 16th and the 27th irrigation. The leachate was collected in a beaker, and the suspended solid was filtered, dried, and weighted. Results (Table 1) show that the highest concentration of suspended solids has occurred in Harkey silt loam previously irrigated with city potable water, and the lowest concentration from a $CaCl_2$ solution (20me L^{-1}). It appeared that soil particle dispersion occurred when distilled water was added. Also note that suspended solids were often higher in city potable water than in either of reclaimed water A or B when leached for the first time. During the second leaching, the concentration of suspended solids decreased, especially in Harkey silt loam. Hueco sandy loam provided the lowest concentration of suspended solids. This soil is highly leached, and contains Fe and Al oxides.

Table 1. Suspended solids and salinity of drainage water following distilled water applications of 3.4 cm on three soils irrigated with various types of water[1]–.

	City Water	Recl. A	Recl. B	Rio Grande	$CaCl_2$
Salinity (dS m^{-1})	0.8	1.4	2.2	0.8	2.2
Sodicity (SAR)	4.4	6.5	11.2	3.5	0
Suspended Solids of Drainage Water (mg L^{-1})					
16th Irrigation					
Harkey silt loam	180	100	70	20	0
Del Norte loam	100	20	30	20	0
Hueco sandy loam	10	5	5	0	0
27th Irrigation					
Harkey silt loam	100	50	10	0	0
Del Norte loam	10	30	40	20	0
Hueco sandy loam	10	0	0	10	0

[1] –The quantity of drainage averaged 1.5 cm per irrigation.

The main shortcoming of this experiment was that the quantity of water applied was limited to 46 cm (18”), although the number of irrigation amounted to a total of 27 events. It is unlikely that the cation exchange reaction has reached a point of equilibrium. The soil moisture condition was also kept on a dry-side through light irrigation of 1.7 cm per application, especially after the 15th irrigation due to an increase in evaporation rate.

Experiment 2. Water Infiltration of Ponded Water: The second experiment was conducted to address the above shortcomings; using three soils: Glendale silty clay loam (Typic Torrifluvent), Turney silty clay loam (Typic Calciorthid), besides Harkey silt loam we used for the first experiment. The soil samples were air-dried and passed through a 4 mm screen. The saline solutions used ranged from EC of 0.5 to 2.0 dS m^{-1}, and SAR of 1.6 and 12.

Ten inch plastic pots contained a 2 cm layer of gravel at the bottom, and a sheet of fiberglass screen over the gravel layer. A thin wall cylinder (15 cm in diameter) was placed on the fiberglass screen. The soil samples were placed inside the cylinder, and a 1:1 mixture of gravel and soil sample was placed in the space between the inner wall of the pots and the outer wall of the cylinder to reduce shrinkage and crack formation. The cylinder was removed while the potted soil was placed on a vibratory table. Once the pots were filled with soil sample and the 1:1 mixture, a PVC ring (10 cm in diameter and 7.5 cm in length) was inserted to a depth of 2.5 cm, providing a 5 cm clearance at the top to accept water application. The outside of the inner ring was filled with the 1:1 mixture to reduce crack formation and upward flow of water. No water was applied to the portion. Water intake measurements were performed after water application to the PVC inner ring.

Upon completion of soil packing, a saline solution having EC of 3.0 dS m^{-1} and SAR of 1 was applied to all pots to a depth of 2.5 cm once a week. This process was repeated for five irrigations to stabilize the soils. The time required for 2.5 cm of water to infiltrate was measured, and the pots were rearranged in a triplicated block design. Thereafter, ten saline solutions shown in Fig. 2 were ponded twice at 5 cm per application. The time required for the last 5 cm of water application was measured until the 15th irrigation. Subsequently, irrigation depth was reduced to 7.5, 5.0 and 2.5 cm per application every four consecutive irrigation. Irrigation was initiated when the soil water storage was reduced to half the maximum storage capacity.

Starting at 28th irrigation, the first three treatments were converted to sodding with fescue, and were irrigated with the saline solutions used for treatments 4, 5 and 6. Prior to seeding, 2 cm of the soil surface was removed from all the pots, air-dried, crushed, placed back, then pressed with a wooden disk until the soil level had settled by about 1 cm from the original level. The irrigation depth of 2.5 cm was maintained. Starting at the 41 or 42nd irrigation, distilled water was applied once to all pots at a depth of 2.5 cm, and the infiltration time measured. The last two irrigations (42 or 43rd) were made using the saline solutions. Soil samples from the region below the PVC ring was removed, air-dried, and saved.

The first half of the infiltration data is summarized in Fig. 2. The infiltration time increased sharply after the 9th irrigation for Glendale (or the 4th irrigation with saline solutions) and the 10th irrigation for Harkey. This corresponds to the cumulative solution application of 40 to 50 cm (16 to 20’’), respectively. Also note that the infiltration of solutions with salinity of 1 dS m^{-1}, was not slower than those with salinity of 2 dS m^{-1}. In fact, water infiltration started slow down first with Solutions 6 and 8. We believe that the cation exchange reaction from low salinity solutions was lagged behind. However, there was no substantive difference in infiltration among different qualities of water applied to Turney silty clay loam (Calciorthid). This is consistent with the previous experimental data with Delnorte gravelly loam (Paleorthid). Combined with the results of this experiment and the first experiment, it would be safe to conclude that upland soils rich in $CaCO_3$ are stable against dispersing effects of Na than alluvial soils.

During the previous experiment, we did not observe the sharp response to water quality, even in Harkey silt loam (Fig. 1). The main difference between the two experiments is the depth and interval of irrigation. It seems to be logical that a prolonged period of wet soil conditions, which has occurred in this experiment, encouraged disaggregation. In addition, the difference in infiltration time is amplified with increasing irrigation depth (Fig. 3). It would be safe to assume that the difference in infiltration times becomes even less when the irrigation depth is reduced to less than 2.5 cm. Recall that the first experiment used 1.7 cm per application. This means the data from this experiment are not different from those of the first experiment, at low rates of water application. The work preformed in Israel has shown that sodicity affects saturated flow more so than unsaturated flow (Russo and Bresler, 1980).

Treatment	NaCl	$CaCl_2$	$CaSO_4$	EC	SAR
	Meq	meq	meq		
1	1.35	3.65	0	0.5	1
2	4.08	0.92	0	0.5	6
3	4.69	0.31	0	0.5	12
4	2.01	7.99	0	1	1
5	7.16	2.84	0	1	6
6	8.9	1.1	0	1	12
7	2.94	17.06	0	2	1
8	16.31	3.69	0	2	12
9	1.35	3.65	7.0	1.7	0.58
10	1.35	3.65	14.0	2.5	0.45

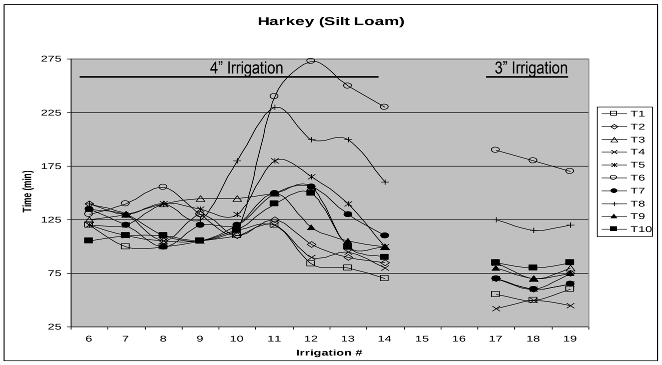


Fig. 2B. The time requires for 1 inch of specified solution to infiltrate in Harkey Soil (Silt Loam)

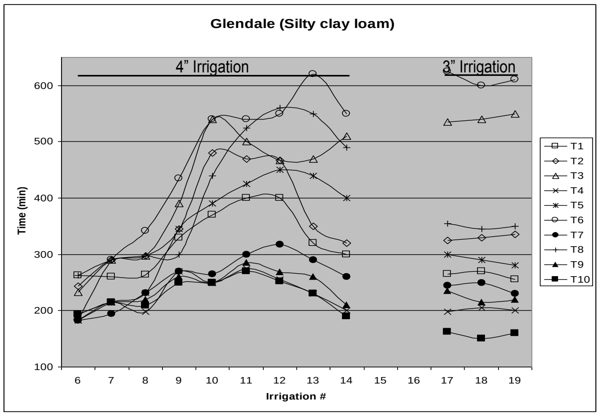


Fig. 2A. The time required for 1 inch of specified solution to Infiltrate in Glendale Soil (Silty Clay Loam)

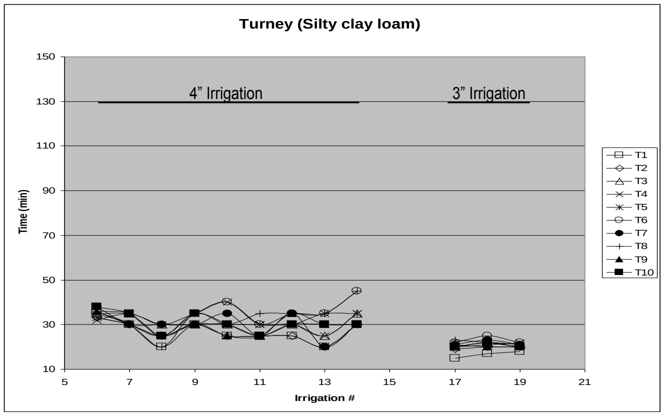
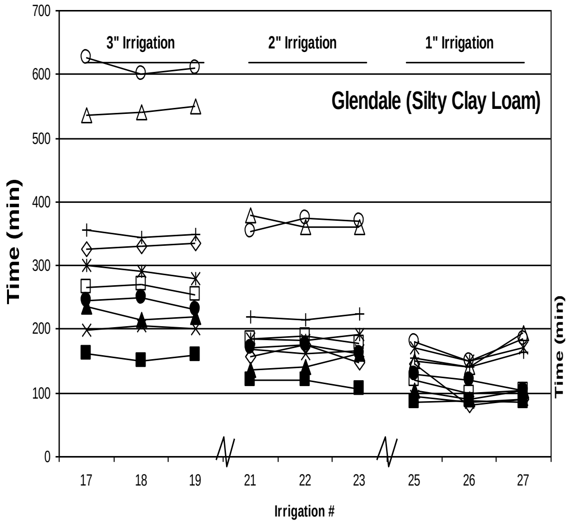


Fig. 2C. The time required for 1 inch of specified solution to infiltrate into Turney Soil (Loam)

Fig. 2. Water quality effect on water infiltration into typical El Paso soils



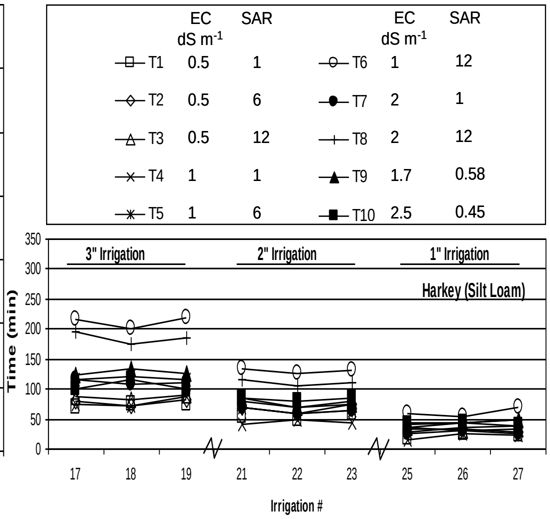


Fig. 3A. The time required for infiltration of different quantities of water into Glendale silty clay loam.

Fig. 3B. The time required for infiltration of different quantities of water into Harkey silt loam.

The remaining question is why water quality effects are so pronounced in alluvial soils, but not in calcic upland soils. We examined soil aggregates before and after the 8th irrigation. Fig. 4 clearly indicates that soil aggregates of Harkey silt loam have slaked with irrigation, while such was not the case with Turney silty clay loam. The photo of Glendale silty clay loam was similar to that of Harkey silt loam, except for smaller particle sizes. Our previous study with Saneli silty clay loam (Torrifluvent) has shown that percentages of soil particles' less than 20μ decreases with lowering salinity and increasing sodicity (Miyamoto, 2006). However, the same study also has shown that nearly all clay particles were flocculated, even under low salinity of 0.7 dS m^{-1} and SAR of 15. The reduction in water intake observed with low salt and high SAR solutions such as Solution 3, 6 and 8 can be attributed to slaking of soil aggregates.

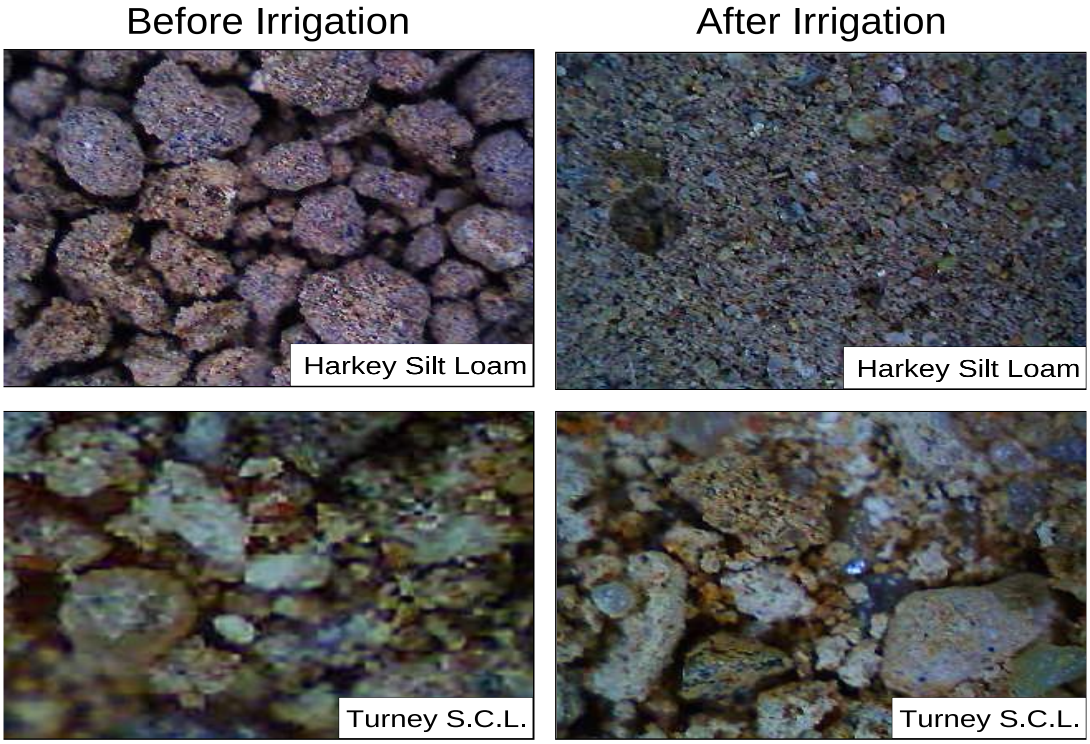


Fig. 4 Microscopic photo (27x27) of Harkey silt loam (Entisol) and Turney silty clay loam (Aridisol) before and after irrigation.

Recall that distilled water was applied to all cases at a depth of 2.5 cm. Results shown in Table 2 indicate that the infiltration time for 2.5 cm of water increased several folds at elevated sodicity, but not at low sodicity. As shown under the first experiment, introduction of distilled water might have caused soil particle dispersion (Table 1). It is likely that particle dispersion and pore plugging compounded the reduction in water intake. The infiltration reduction caused by soil surface phenomenon, such as particle dispersion at the soil surface may not be detected by the conventual analysis of EPS. It is related directly to water quality, and may explain the lysimeter data obtained by Oster and Schoer (1979) where water infiltration had better correlation with water quality than with soil salinity.

Table 2. The infiltration time of one inch of saline solutions or of distilled water in two alluvial soils

Treatments	EC	SAR	Glendale Silty Clay Loam			Harkey Silt Loam		
Sodded			Solution	Distilled	Increase	Solution	Distilled	Increase
					%			%
1	1	1	68a	130b	91	25a	30a	20
2	1	6	68a	235b	245	27a	67b	148
3	1	12	190a	475b	150	29a	115b	296
Bare			Solution	Distilled	Increase	Solution	Distilled	Increase
					%			%
4	1	1	94a	90a	0	28a	30a	7
5	1	6	180a	280b	55	45a	69b	53
6	1	12	240a	390b	63	80a	160b	100
7	2	12	170a	360b	110	60a	161b	168
8	1.7	0.7	125a	165b	32	42a	99b	136

*Numbers in row followed by the same letter are not significantly different between the columns

Recall that the original treatments 1, 2 and 3 were changed to sodded surface, and all potted soils were pressed, starting at the 28th irrigation. Fescue sods, although small seedlings of 30 each per 78 cm^2 helped reduce the infiltration time significantly (Table 3). By this time, water infiltration into bare soil, especially those irrigated with water of SAR of 6 and 12 have further reduced, probably due to the compaction imposed and aggregate slacking at and near the soil surface. The reduced infiltration time observed in sodded pots is in part due to drier soil conditions prior to irrigation. However, even when the soil water content prior to irrigation was kept the same between sodded and nonsodded pots, the infiltration rate was faster in the sodded pots. It is entirely possible that the presence of live plants reduced dispersion at or near the soil surface.

Table 3. Effects of sodding (Fescue seedlings) on infiltration time of one inch solutions

Water Quality		Glendale Silty Clay Loam			Harkey Silt Loam		
EC	SAR	Sodded	Bare	Reduction	Sodded	Bare	Reduction
		---------min---------		%	---------min---------		%
1	1	68a *	94b	-28	25a	28a	-11
1	6	68a	180b	-62	27a	45a	-40
1	12	190a	240b	-21	39a	80b	-31

*Numbers in row followed by the same letter are not significantly different between the columns

Experiment C. Soil Column Infiltration and Permeability Experiment: The greenhouse pot experiment used above required lots of time and skilled workers, and can not be used for routine testing. Infiltration and permeability measured in small soil columns would be a simpler option, provided that the soil column data have a meaningful correlation with the greenhouse data. For evaluating this potential, the soils used for the greenhouse experiment were removed from the region directly under the infiltration ring. They were air-dried, passed through a rod mill for 5 seconds, and passed through a 2mm screen. The samples were packed into Plexiglas columns (1.98 cm ID, 7.5 cm long) at two bulk densities (low and high compaction) to a thickness of 2.5 cm. Saline solutions used for Treatment 5, 6, 7, 8 and 9 were applied to a depth of 5 cm, and water intake measured in duplicate in Harkey and Glendale soils. Low and high compaction respond to 2 and 8 drop impact of a mini-compaction rod, which yields the same impact pressure as the ATSM compaction rod. Results indicate that soil column intake data were influenced by the degree of compaction and the quality of the solution used (Fig. 5). The order of intake reduction was consistent with the long-term greenhouse data shown earlier. Also recall that the initial infiltration data did not reflect the long-term changes in infiltration caused by water quality (Fig. 3). The fact that water infiltration into these soils differed significantly indicates that quick infiltration tests preformed in small soil columns reflect to soil properties, more so than the quality of water being applied, except for the case of distilled water or water of low salinity.

As a supplement, we also collected field samples from a municipal park, where reclaimed water (EC = 2.1 dS m^{-1}, SAR of 11) has been used for the last 12 years. Two samples came from the irrigated area, and two samples from nonirrigated area, about 6 m (20 ft) away. The soil samples were processed as before, and a saline solution with EC of 2.0 dS m^{-1} and a SAR of 12 was applied. Distilled water was also used for a comparison. Results shown that the sample from nonirrigated area (native) responded to compaction, but not much to application of distilled water (Fig. 5A), probably because of low soil sodicity. The sample from the irrigated area responded to both compaction and distilled water application. This dataset seems to confirm that infiltration measurements in small columns could be useful for making a comparison of infiltration response to soil properties. However, it would not be a predictor of water infiltration after a prolonged use of water of elevated sodicity, until additional data such as shown in Fig. 5B becomes available for Entisols.

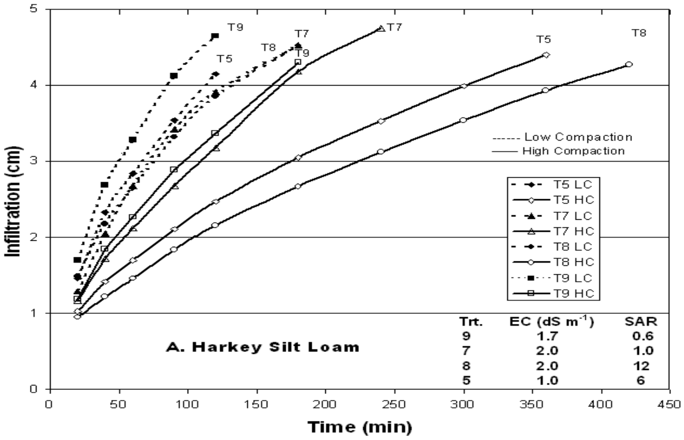


Fig. 5A. Infiltration of saline solution into Harkey silt loam previously irrigated with the same solutions. LC: Low compaction.

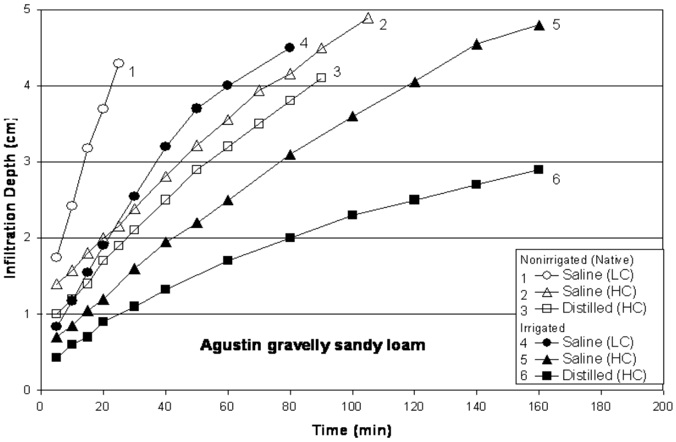


Fig. 5B. Infiltration of simulated reclaimed water and distilled water into Agustin gravelly loam collected from nonirrigated and irrigated sites.

Acknowledgment

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