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Vertical Transport of Water and Chemicals as Affected by Soil Layering: A Model Study

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ABSTRACT

Transport of water and chemicals in soils is controlled by soil properties and processes. Advection, adsorption, diffusion, and dispersion of the chemical are the main processes controlling the extent of transport of a chemical. Soil porosity and pore size distribution are the key factors controlling the water and solute flow by advection and dispersion, soil adsorption phenomena are the main factors controlling the retention of the chemical in soils. All these processes are highly variable by depth due to differences in soil characteristics of different soil horizons. This study was conducted to analyze interactions between soil layering and vertical transport of solutes and water at 2-m wide, 4-m long, and 0.5-m deep lysimeters constructed as field plots. Zero, five, ten, fifteen, and twenty cm thick sand layers (as treatments) were placed over a level alkaline surface, then 30 cm thick non-alkaline soil layers were packed over the sand layers. To represent plant effect, alfalfa was grown at each plot since it has a dense canopy. Changes in pH, EC, and in concentrations of Na, K, HCO_3, and B in topsoil were monitored, measuring these variables in water extracts collected by vacuum samplers following rainfall and/or irrigation events. Water content of both repacked topsoil and alkali subsoil were measured in October, 2004 when soil was dry. At the final sampling, a representative profile was open in each research plot and morphological observations were made in these profiles. Soil pH decreased and then increased sharply irrespective to sand layer thickness, and concentrations of HCO_3 and B showed a similar behavior. The EC of repacked topsoil decreased continuously probably due to the leaching of salts by application of excess amount of irrigation water, and Na concentration of soil solution increased continuously, which was attributed to sodium transported by capillary rising water from the blow alkali soil. Greater values for water content occurred at final sampling in alkali soil below 5- and 0-cm sand layers, indicating that sand layer with 10 cm thickness obscured percolation of excess water from irrigation and precipitation as observed in layered soil profiles. Roots of alfalfa concentrated in the zone of sand layers, and almost no roots of alfalfa penetrated into the alkali zone in search of water and nutrients. As morphological observations revealed, channels of decayed roots in the alkali soil served as preferential pathways of water and chemical from upper layers.

Keywords: Soil layering, chemical transport, water flow, sand layer, alfalfa

INTRODUCTION

Soil layering greatly affects water and chemical transport in downward and upward directions due to differences in hydraulic characteristics of soil layers. The soil layer with lowest conductivity attains the magnitude of water and chemical transport in layered soil profiles (Hillel, 1980). While downward transport is important for transport of agrochemicals and their derivatives toward groundwater, upward transport is important in the case of transport of salts from water table to root zone, resulting in salinity and alkalinity of the soils. Preferential flow may contribute significantly the downward movement of water and chemicals in saturated conditions (Jarvis, 2007; Clothier et al., 2008). The extent of preferential flow is controlled by structural formations such as soil cracks, inter-aggregate spaces, and biological features such as root channels and wormholes. All these may differ significantly by layers (Vanclooster, et al., 1995). Ersahin et al. (2002) related preferential flow in A and B_w horizons with a well-developed macroporosity and equilibrium transport in E horizon that lacked macropores.

Characteristics of water flow and chemical transport in layered soils have been studied extensively. Majority of these studies have been conducted in controlled conditions of laboratory column studies and lysimeters in relatively short time scales. The purpose of this study was to assess soil layering influence on vertical transport of matter in plot scale in relatively longer time. This paper reports the data collected and observations made in the first two years of this long-term experiment.

MATERIAL and METHODS

A field trial, as complete randomized blocks with five treatments and three replicates, was designed (Fig.1a). Each parcel in the Fig.1a was a 4-m by 2-m by 0.5 m lysimeter supported by metal frames around (Fig. 1b). The parcels in the Fig.1a were built on level surface of alkali soil. The purpose of using alkali soil was to evaluate the vertical transport of sodium and other substances by capillary ascent from alkali soil to the non-alkali soil repacked over the sand layer. Sand, screened with a 2-mm sieve, was located over the alkaline surface. Finally, soil provided from a nearby river bed was located over the sand layer (Fig. 1c). The sand layers with 0, 5, 10, 15, and 20 cm were the treatments of the complete randomized block design. To account for plant effect, alfalfa was grown at the plots (Fig. 2).

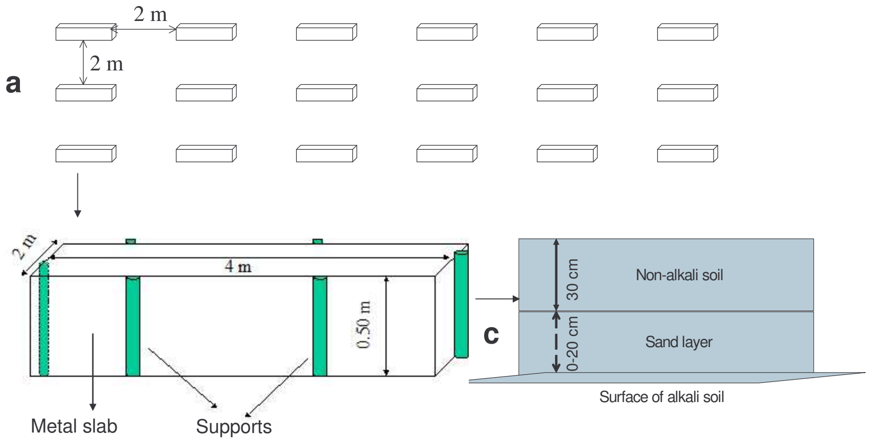

Fig 1. Layout of field trial with details of plots.

Fig 2. View of field trial with alfalfa grown at the plots.

To determine the initial conditions, soil samples were taken from below alkali soil and non-alkali soil in each parcel. The soil sampling was repeated in the fall of 2003 and 2004. The parcels were irrigated when needed. At the soil sampling, observation for plant root development and other visual features were made in representative profiles of parcels. The soil samples were transported to laboratory and analyzed for soil texture with a Bouyoucos hydrometer (Gee and Bouder, 1982), soil pH and EC with a glass electrode (McLean 1982) Na, Ca, and Mg with a flame photometer. Cation exchange capacity of the soils were measured by the method given by Rhoades (1982). Bulk density was measured in non-alkali soil, after repacking, with undisturbed soil samples taken with 100 cm^3 steel cores (Blake and Hartge, 1986). Soil particle size distribution was measured once, while other properties were measured at each sampling. The data were evaluated by ANOVA.

Vacuum soil samplers were installed in 20 cm depth of non-alkaline soil (Fig. 3). Concentration of soil solution Na, K, B, HCO3 and values of EC and pH were measured in water samples taken by porous samplers to monitor changes the soil solution concentration of these chemicals.

Fig 3. Vacuum soil water samplers at the plots

RESULTS and DISCUSSION

Initial conditions for alkali soil and non-alkali soil over the sand layers are given in Table 1. The alkali soil is clay with considerably high pH. The EC of alkali soil is not high enough to designate it as a saline-alkali soil. The silty loam soil placed over sand layers is slightly salty (Table 1).

Table 1. Properties of alkali soil and non-alkali soil repacked at the plots

Soil property	**Non-alkali soil**	**Alkali soil**
CEC (cmol kg^{-1})	22.00#	30.40
Na (cmol kg^{-1})	3.80	18.40
K (cmol kg^{-1})	1.28	1.02
Ca+Mg (cmol kg^{-1})	17.18	11.6
pH	8.3	9.4
EC dS cm^{-1}	700	2270
CO_3^{-2} meq/L	1.0	10
HCO_3^- meq/L	9.9	90
Sand (%)	26	20
Silt (%)	53	23
Clay (%)	21	57
Texture class (USDA)	Silty loam	Clay

#The values are mean of 15 samples.

The values of bulk density (Mg m^{-3}) of the repacked topsoil achieved in each plot, after repacking, are shown in Table 2. Bulk density values are highly similar one to another, indicating that a uniform repacking was achieved.

Table 2. Bulk density (Mg m-3) of the topsoil after repacking

Replicates	Treatment (thickness of sand layer placed between alkali soil and repacked topsoil)				
	0	5	10	15	20
1	1.20	1.08	1.20	1.08	1.09
2	1.11	1.24	1.14	1.07	1.12
3	1.07	1.02	1.12	1.14	1.18
Mean	**1.13**	**1.11**	**1.15**	**1.10**	**1.13**

Changes in Soil Solution Composition in Non-alkali Soil

During the experimentation, soil water samples, taken from repacked topsoil using vacuum samplers, were analyzed for pH, EC, HCO_3, Na, K, and B. The results are given in a series of figures (Figs 4 and 5). Soil pH decreased and then increased sharply in all the treatments. Concentrations of HCO_3 and B followed a similar trend but their final increase was not as sharp as of pH. The effect of sand layer thickness between alkali soil and repacked non-alkali topsoil was insignificant. The EC of non-alkali topsoil decreased gradually, which was attributed to the continuous leaching of salts as alfalfa in the plots (Fig.2) was irrigated excessively.

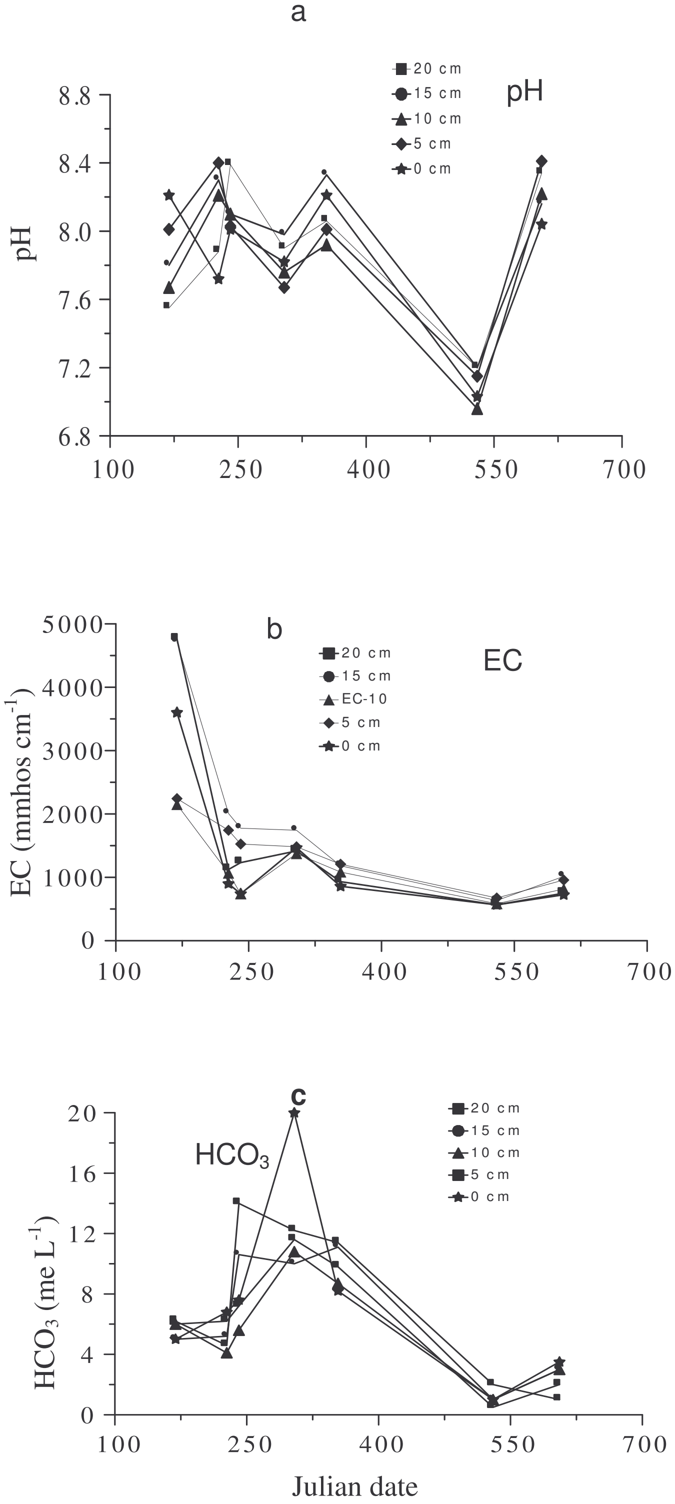

Fig 4. Changes in (a) pH, (b) EC, and c) HCO_3 in solution of repacked topsoil, located over 0, 5, 10, 15, and 20 cm thick sand layers on an alkali soil surface. The observation starts on the 100th day of the year 2003.

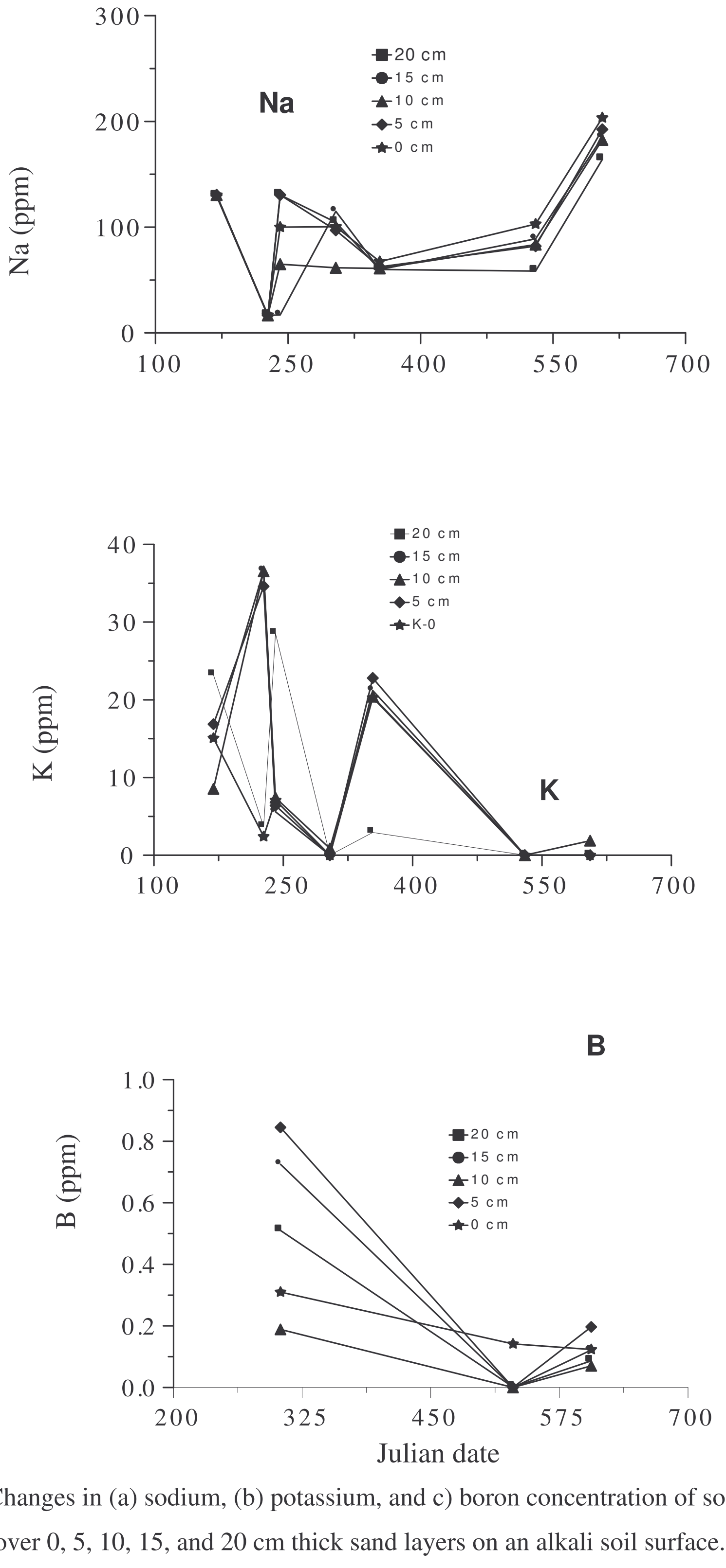

Fig 5. Changes in (a) sodium, (b) potassium, and c) boron concentration of solution of repacked topsoil, located over 0, 5, 10, 15, and 20 cm thick sand layers on an alkali soil surface. The observation starts on the 100th day of the year 2003.

Sodium concentration of soil solution increased continuously, which was attributed to the fact that some sodium was transported by capillary rising water from the blow alkali soil. The greatest increase in Na concentration occurred in 0 cm sand layer, while lowest occurred in 20 cm sand layer, indicating that the sand obscured transport of Na by capillary rising. Potassium does not leach in the soils with medium texture. However, the Fig.5 shows that K concentration of soil solution in the repacked topsoil generally decreased. This was attributed to that alfalfa would consume readily available K in the soil solution as no fertilizer was used in the second year of experiment.

Water Content of Repacked Topsoil and Alkali Soil

Water content of both repacked topsoil and alkali soil below the plots were measured on the last day (in October, 2005) of the two-year experimentation. Results are shown in Table 3. Expectedly, water content vales obtained for repacked topsoil were highly similar. However, interestingly, the greater values for water content were obtained for alkali soil under 5- and 0-cm sand layers.

Table 3. Water content (on the weight basis) of repacked topsoil and alkali soil under sand layers with different thickness

Treatment	**Water content (%)**	
	Repacked topsoil	**Alkali soil**
B1-0#	10.15	27.81
B2-0	8.75	28.01
B3-0	10.84	na
Mean	**9.91**	**27.91**
B1-5	9.60	31.48
B2-5	8.98	30.53
B3-5	10.57	na
Mean	**9.72**	**31.01**
B1-10	7.88	14.76
B2-10	7.23	na
B3-10	10.24	14.93
Mean	**8.45**	**14.84**
B1-15	10.22	na
B2-15	8.32	15.56
B3-15	10.20	16.31
Mean	**9.58**	**15.94**
B1-20	10.88	15.54
B2-20	8.08	16.68
B3-20	10.02	na
Mean	**9.66**	**16.31**

#The notation B1-0 indicates the first replicate of treatment 0-cm thick sand layer.

na: Not available

As reported by Jury et al. (1992), Gardner demonstrated how a sand layer located below a clay layer impeded water flow from the clay layer to the sand layer, showing that water could not penetrate into the sand layer unless some positive pressure to form over the sand layer. Hillel and Baker (1988) proposed that instabilities arise whenever difference in hydraulic conductivity at the water supply suction occurs between soil layers. Therefore, we suspected a similar effect of sand layer in the plots. Similar proposals were made earlier by Saffman and Taylor (1958). That 5-cm thick sand layer behaved similar to 0-cm one would be attributed that the thickness of sand layer would be critical in obscuring the vertical flow of water in layered soils.

Morphological Observations

At the final soil sampling, representative profiles were open in plots for morphological observation and photographing. Interestingly, the roots of alfalfa concentrated in sand layers, which is poor in nutrients (Fig. 6).

Fig 6. Roots of alfalfa considerably proliferated and concentrated in the sand layers located under non-alkali soil.

Almost no roots of alfalfa detected in the alkali zone in search of water and nutrients. However, water and other substances from the upper zone penetrated into the alkali zone through channels of decayed roots from the weeds that died as they were covered by the overlying material (Fig.7).

Fig 7. Decayed roots of weeds previously grown in the alkali soil. The roots decayed after the soil surface had been covered with sand and non-alkali soil. The decayed root channels served as preferential pathways for the water and solutes transported from overlying non-alkali soil.

CONCLUSIONS

This model study was conducted to investigate vertical transport of water and chemicals in artificially layered soil profiles. The sand layer located between alkali and non-alkali soil over the sand layer obscured both upward and downward flow of water as expected. Also, decayed root channels in alkali soil served as preferential pathways for water and chemicals from the upper zone. Localities around the decayed roots were colored differently, indicating improvements in the alkali soil. This may be an alternative way of remediation of strongly alkali soils. Interestingly, the roots of alfalfa concentrated in the sand layer, which is poor in nutrients. The time duration of the experiment was insufficient for an adequate investigation of the effect of treatments. Therefore, the experiment still continues for future investigations.

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