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A laboratory study of the effects of water dissolved gypsum application on hydraulic conductivity of saline-sodic soil under intermittent ponding conditions

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Reclamation of saline-sodic soils has great importance in agricultural management. The objective of this study was to evaluate the effectiveness of the methods used to apply water and gypsum on hydraulic conductivity of a saline-sodic soil with an electrical conductivity of 28 dS/m and exchangeable sodium percentage of 46%. The experiment was conducted under laboratory conditions using disturbed and non-cropped soil columns. A total of 45 cm of water was applied to each column with 3, 6, or 9 separate water applications. Finely ground gypsum (< 0.5 mm maximum particle diameter) was either incorporated into the surface 2 to 3 cm of soil or was dissolved into the leaching water at a rate corresponding to 3.82 t/ha. Six or nine separate water applications of gypsum dissolved into leaching water significantly increased hydraulic conductivity (P < 0.01). Soil hydraulic conductivity increased (P < 0.01) with depth at separate applications of gypsum.

Keywords: Gypsum; hydraulic conductivity; saline-sodic soil

Introduction

The primary limitation for reclaiming saline-sodic soils is low hydraulic conductivity. Hydraulic conductivity of soils decreases with increasing soil exchangeable sodium percentage (ESP) and decreasing total electrolyte concentration of soil solution (Moutier, Shainberg and Levy, 1998; Oster, Shainberg and Abrol, 1999). Higher ESP increases clay swelling, dispersion of clay, and favors the formation of a surface crust (Ilyas, Miller and

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Qureshi, 1993). In saline-sodic soils, swelling and dispersion of soil aggregates causes the size and number of water-conducting pores (macropores) to decrease and results in slow leaching (Abu Sharar, Bingham and Rhoades, 1987; Ilyas, Qureshi and Qadir, 1997).

Providing a source of Ca can reclaim saline-sodic soils. Calcium flocculates clay minerals resulting in aggregation. Gypsum is the source of Ca most commonly used (Oster, 1982). The macroporosity of soils is stabilized by treatment with gypsum, and the concentration of Ca electrolyte maintained in the soil solution prevents the disruption of aggregates and the occlusion of pores by dispersed clay particles (Greene *et al*., 1988). The gypsum used may be either dissolved in leaching water or incorporated into soil, or left at the surface (Simunek and Suarez, 1997; Oster *et al*., 1999). The agricultural-grade gypsum used for reclamation of sodic soil usually is passed through a 30-mesh sieve (<0.5 mm) (Hira and Singh, 1980). In most countries fine gypsum grades are used, because they dissolve more rapidly in water (Elshout and Kamphorst, 1990).

When gypsum is applied at higher rates, it is usually mixed at a greater soil depth. But, Oster (1982) reported that the effect of depth of mixing on gypsum dissolution was small in such cases. Gupta, Singh and Abrol (1985) observed that the depth of mixing had no effect on gypsum dissolution. Hira and Singh (1980) reported that about 4 cm of water per unit area was sufficient to dissolve all agricultural grade gypsum present in the soil which had particle size of <0.26 mm.

The dispersion of clay and its subsequent lodgment in soil pores is responsible for reduction in soil hydraulic conductivity when the percolating water is low in electrolyte concentration (Abu Sharar *et al*., 1987; Simunek and Suarez, 1997; Minhas *et al*., 1999). Oster and Schroer (1979) showed that the ponded infiltration rate into undisturbed soil columns was controlled by the chemical properties of the infiltrating water.

Three methods of leaching water application; continuous ponding, intermittent ponding and sprinkling are commonly used. The water requirement for leaching can be reduced by intermittent applications of ponded water, particularly for fine-textured soils. However, intermittent ponding techniques may be slower than continuous ponding (Oster *et al*., 1999). Continuous ponding, although using more water, removes the salts more quickly (Oster, Willardson and Hoffman, 1972).

The objective of this study was to evaluate the effectiveness of methods used to apply leaching water and gypsum on the hydraulic conductivity of a saline-sodic soil.

Materials and Methods

This study was conducted under laboratory conditions with a relative humidity of 50 ± 5%, and average temperature of 18 ± 2 °C. A saline-sodic soil (Typic Natrargid, USDA (1998)) was used in the experiment. Some physical and chemical properties of the soil used are shown in Table 1.

Air-dried soil sieved through a 1 cm mesh was filled into 27 drainage-type plastic columns 50 cm long and 30 cm diameter to a depth of 30 cm. The soil columns were tapped 25 times after each 10 cm soil addition. The bulk density of the columns was approximately 1.36 g/cm^3.

For each column, gypsum (3.82 t/ha) and leaching water (45 cm/ha) as intermittent ponding was applied. The particle size of gypsum used in this study was <0.5 mm. Good quality leaching water with the following characteristics was used: Ca 0.8 mmol/l; Mg 0.3 mmol/l; Na 0.3 mmol/l; K 0.1 mmol/l, HCO_3 1.3 mmol/l; electrical conductivity 0.26 dS/m; sodium adsorption ratio 0.29; pH 7.9.

Table 1. Some properties of the soil studied

Characteristic	Value
Clay (g/kg)	390
Silt (g/kg)	370
Sand (g/kg)	240
Porosity (%)	49.6
Field capacity (g/kg)	278
Organic matter (g/kg)	6
Electrical conductivity (dS/m)	28.0
pH	9.7
Exchangeable Na (mmol/kg)	98
Cation exchange capacity (mmol/kg)	215
Exchangeable sodium percentage	45.6
Calcium carbonate (g/kg)	40
Cations (mEq/kg)	
Ca^{2+}	1.57
Mg^{2+}	1.25
Na^{+}	23.82
K^{+}	0.03
Anions (mEq/kg)	
CO_3^{2-}	0.08
HCO_3^{-}	4.1
Cl^{-}	18.11
SO_4^{2-}	8.06

Gypsum was incorporated into the surface soil (S) or dissolved in the leaching water (D). Leaching water was applied as 3 (T3), 6 (T6), or 9 (T9) separate applications (Table 2). No gypsum was added to the control columns. In this study each treatment was replicated 3 times.

After the first application, subsequent leaching water was applied 24 h after full infiltration of the previous application. The water was applied by hand within a 2 min period which resulted in surface ponding. A strainer was used in order not to destroy the soil surface.

Following leaching, soil samples were taken from each 10 cm layer for determination of electrical conductivity, exchangeable sodium percentage and hydraulic conductivity. Undisturbed soil samples, taken using soil samplers 5 cm long and 5 cm diameter, were used for hydraulic conductivity measurements. Hydraulic conductivity was calculated from the values recorded under saturated conditions with a constant head permeameter (Klute and Dirksen, 1986), electrical conductivity was measured by EC-meter in saturated extract (Rhoades, 1982a), cation exchange capacity was determined by the sodium acetate method (Rhoades, 1982b), and exchangeable sodium was determined according to Knudsen, Peterson and Pratt (1982).

Table 2. Gypsum and leaching water treatments

Gypsum treatment	Water application method			Remarks
	T3	T6	T9	
S	3 × 15 cm	6 × 7.5 cm	9 × 5 cm	Whole gypsum (3.82 t/ha) was incorporated into the surface 2 to 3 cm of soil before leaching.
D	3 × 15 cm	6 × 7.5 cm	9 × 5 cm	Gypsum was dissolved in the leaching water at a concentration that yielded an application rate of 3.82 t/ha in a total water application of 45 cm/ha.
Control	3 × 15 cm	6 × 7.5 cm	9 × 5 cm	No gypsum applied.

Analysis of variance was carried out as split plot design using the MSTAT-C statistical program (MSTAT-C, 1988). Gypsum and leaching water factors were treated as main plots, soil depth as the sub plot. Duncan's multiple range test was used for comparisons of means.

Results and Discussion

The methods used to apply gypsum and leaching water had different effectiveness on the hydraulic conductivity of the saline-sodic soil used in this laboratory experiment. Soil hydraulic conductivity was increased ($P < 0.01$) by gypsum application. The highest hydraulic conductivity was obtained for the D treatment. The overall difference between the D and S treatments was statistically significant ($P < 0.01$).

The protocol used to apply the leaching water also had an important effect on hydraulic conductivity ($P < 0.01$). The highest hydraulic conductivity was obtained from the T6 method for water application and differences between the T3 and T6 methods were significant ($P < 0.01$).

In the D treatment, increasing the number of leaching water applications increased hydraulic conductivity ($P < 0.01$), but there was no significant difference between the T6 and T9 methods (Table 3). The differences among water application methods were unimportant for the control treatment. Hydraulic conductivity is especially sensitive to low electrolyte concentration. Thus, mixing gypsum into the soil or its direct addition to water, can potentially increase hydraulic conductivity of soils (Oster and Frenkel, 1980; Oster, 1982).

Differences in hydraulic conductivity values were also observed with soil depth. Within the D treatments, hydraulic conductivity increased with soil depth (Table 3). The hydraulic conductivity of the 20 to 30 cm layer was higher than that of 0 to 10 cm layer ($P < 0.01$). The highest hydraulic conductivity in all layers was obtained from the D treatment.

Within the S treatments hydraulic conductivity decreased with depth for the T3

Table 3. Mean hydraulic conductivity for gypsum treatment × water application method, gypsum treatment × depth, and water application method × depth

Treatment configuration	Hydraulic conductivity (cm/h)
Gypsum treatment × Water application method	
S × T3	0.091 [bc**]
S × T6	0.099 [b]
S × T9	0.087 [c]
D × T3	0.092 [bc]
D × T6	0.112 [a]
D × T9	0.115 [a]
C × T3	0.024 [d]
C × T6	0.023 [d]
C × T9	0.024 [d]
Gypsum treatment × Depth	
S × (0 to 10 cm)	0.080 [d]
S × (10 to 20 cm)	0.101 [bc]
S × (20 to 30 cm)	0.095 [c]
D × (0 to 10 cm)	0.097 [bc]
D × (10 to 20 cm)	0.105 [b]
D × (20 to 30 cm)	0.116 [a]
C × (0 to 10 cm)	0.030 [e]
C × (10 to 20 cm)	0.023 [ef]
C × (20 to 30 cm)	0.019 [f]
Water application method × Depth	
T3 × (0 to 10 cm)	0.077 [ab]
T3 × (10 to 20 cm)	0.069 [bcd]
T3 × (20 to 30 cm)	0.062 [cd]
T6 × (0 to 10 cm)	0.070 [bc]
T6 × (10 to 20 cm)	0.081 [a]
T6 × (20 to 30 cm)	0.083 [a]
T9 × (0 to 10 cm)	0.060 [b]
T9 × (10 to 20 cm)	0.080 [a]
T9 × (20 to 30 cm)	0.085 [a]

[1]Depth = Soil horizon. See Table 2 for definitions of gypsum treatments and water application method.
[abcde]Means, within treatment configuration, without a common superscript differ significantly ($P < 0.01$).

treatment, but increased with depth for T6 and T9. Within the T6 and T9 treatments, the hydraulic conductivity of the 10 to 20 cm and 20 to 30 cm layers were higher than that of 0 to 10 cm layer ($P < 0.01$).

Hydraulic conductivity increased with depth for all water application methods with the D treatment (Figure 1). The hydraulic conductivity of the T6 and T9 application methods was higher than those of the other treatments for the D treatment. However, for the T3 treatment the hydraulic conductivity was higher in the 0 to 10 cm and 10 to 20 cm layers in the S treatment compared with 20 to 30 cm layer but was higher in the 20 to 30 cm layer for treatment D.

The hydraulic conductivity of soil decreases as the proportion of exchangeable soil Na increases and as total electrolyte concentration of the soil solution decreases (Moutier *et al*., 1998; Oster, Shainberg and Abrol, 1999). After leaching, the ESP value for the D treatment (17.2, s.e. 0.2, %) was lower than that for the S treatment (19.6, s.e. 0.8, %), while the EC value for treatment D (1.22, s.e. 0.03, dS/m) was higher than for treatment S (1.14, s.e. 0.05, dS/m). In the control treatment hydraulic conductivity was extremely low due to the high ESP and low salinity. The lower ESP and higher EC values for treatment D can explain the higher hydraulic conductivity for this treatment.

The higher hydraulic conductivity for the D treatment as compared to the S treatment could be explained by the electrolyte concentration of the leaching water (Oster and Schroer, 1979; Oster *et al*., 1999). Ishiguro and Nakajima, (2000) found that hydraulic conductivity decreased using leaching water with lower electrolyte concentration When gypsum is dissolved in leaching water, the electrolyte concentration of water increases (Oster, 1982; Ramirez, Rodriguez and

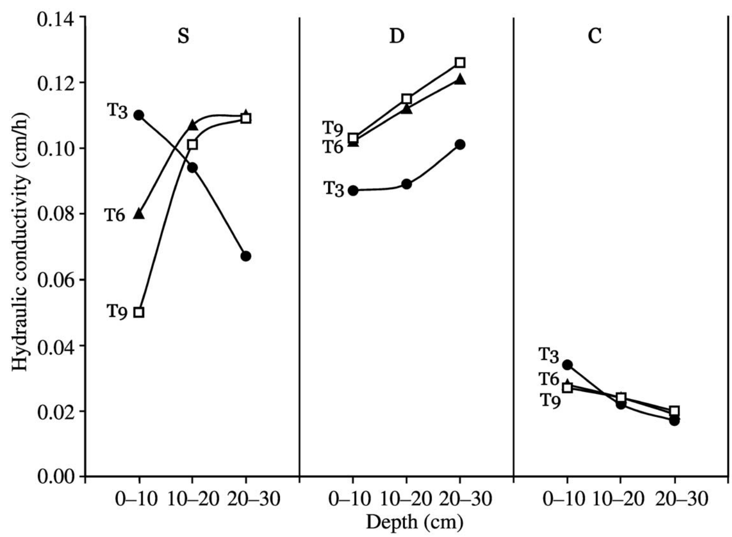

Figure 1: The variation of hydraulic conductivity with soil depth for all combinations of gypsum treatments (S = whole gypsum incorporated into top 2 to 3 cm of soil, D = gypsum dissolved in leaching water, C = no gypsum applied) and application methods (fixed volume of water as 3 (T3), 6 (T6) or 9 (T9) separate applications).

Shainberg, 1999). The positive effect of electrolyte concentration on hydraulic conductivity could be maintained for longer by applying such leaching water over a number of applications. The long-term electrolyte effect of gypsum is very important for a chemically stable soil (Shainberg, Keren and Frenkel, 1982).

For the D treatment, hydraulic conductivity increased with depth and the application of leaching water as more split applications increased this positive effect. This might be explained by greater Ca transport from the upper soil layer (Oster, 1982) leading to increased hydraulic conductivity in the lower layers.

It is possible to conclude that the application of gypsum dissolved in water would decrease the ESP value under field conditions. When gypsum dissolves in the leaching water, free calcium is released. This does two things, it decreases the sodium adsorption ratio because there is more calcium compared to sodium and it increases salinity. Both of these actions improve the aggregation of soil particles and, thereby, reduce surface sealing and improve infiltration (Kern Soil and Water, 2004).

A gypsum applicator, which consists of a tank with agitation paddles and an injection pump, can be used to apply the gypsum dissolved in water. Finely ground gypsum is mixed with water to form a slurry which is then injected into the leaching water (Wheeler and Brown, 1999).

Results of this study clearly show that soil hydraulic conductivity increased with application of gypsum dissolved in water in agreement with our previous work (Sahin, Oztas and Anapali, 2003). It is concluded that the hydraulic conductivity of soil can be improved by applying gypsum dissolved in leaching water and split into six or more applications.

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