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MECHANISMS OF HYDRAULIC CONDUCTIVITY REDUCTION IN THE KHURRIANWALA SOIL SERIES

S.A. Shahid & D.A. Jenkins*
Department of Soil Science,
University of Agriculture, Faisalabad
**School of Agricultural & Forest Sciences,*
University of Wales, Bangor, U.K.

Samples from various layers of the Khurrianwala soil series (Natric camborthid) were subjected to hydraulic conductivity measurements. Hydraulic conductivity was measured with a set of treatments 1) distilled water (DW), 2) gypsum saturated solution (GSS), and 3) GSS + deep ploughing. The results revealed the operation of dispersion, translocation and deposition of clay particles into the conducting pores as the dominant mechanism in the upper three layers (0-5, 5-10 and 25-30 cm), whereas swelling in three deeper layers (45-50, 65-70 and 125-130 cm).

INTRODUCTION

The hydraulic conductivity (HC) of the soil is either reduced by dispersion of clay particles and their subsequent deposition in the conducting pores or through swelling. The importance of dispersion in affecting soil permeability was recognised by Felhendler *et al.* (1974) and Shainberg *et al.* (1981 a, b). Recently Yousaf *et al.* (1987) discussed the clay dispersion with respect to HC of the soils. McNeal *et al.* (1968) reported a linear relationship between the HC reduction and macroscopic swelling of extracted clays. The swelling of clay may be crystalline swelling (Norish, 1954; Norish and Quirk, 1954) or osmotic swelling (El-Swaify and Henderson, 1967; Van Olphan, 1977).

The measurement of soil HC is of great importance in practical agriculture since related to the movement of soluble salts and nutrients. It also helps to forecast the drainage capacity of the soil for agriculture and engineering purposes and provides indirect informations of soil structure.

The present project was started to assess the hydraulic conductivities of the dense saline-sodic soil profile, Khurrianwala soil series (Natric Camborthid) under simulated rain conditions and improvement by gypsum and finally with gypsum and deep ploughing. Moreover, it was aimed to elucidate the important mechanisms operating in the soil profile that can result in the reduction of soil permeability.

MATERIALS AND METHODS

Bulk samples were collected from 0-5, 5-10, 25-30, 45-50, 65-70 and 125-130 cm depths of the Khurrianwala soil series (KWSS). Physical and chemical measurements were made on the soil (<2 mm) according to the standard methods (Page *et al.*, 1982), except otherwise mentioned. Soil texture was determined according to Day (1965) and the textural class was determined on the basis of particle size grades of the British Standards Institution and the Massachusetts Institute of Technology-MIT (Hodgson, 1976).

The values of EC_e, pHs and exchangeable sodium percentage (ESP) of all the samples of the KWSS classified them as saline-sodic (Richards, 1954). The textural class (Hodgson, 1976) is silty clay loam in all but the 0-5 and 5-10 cm samples where it is sandy silt loam (Table 1).

Preparation of soil columns for HC measurements: The material used for the preparation of soil columns is a glass tubing of 2 mm thick wall with an internal diameter of 31 mm and a length of 200 mm. The ends of the columns were heated up to 1200 °C to make them round.

The soil columns were prepared by placing the glass wool at the lower end of each column and a circular nylon cloth (200 μm opening) was placed between the soil and glass wool. The lower end of each column was then wrapped by the nylon cloth as stated above and retained by rubber bands.

Processed soil (120 g) was fed into the columns using a wide mouthed funnel of 10 mm outlet diameter, made by cutting the long end off the funnel. Tapping of the soil columns to achieve a particular bulk density was not done in order to avoid stratification. The surface of the soil in columns was covered by the quartz sand about ½ cm thick.

Treatments/saturation of soil columns: The soil columns were saturated with distilled water (DW) according to Klute (1965). The saturated columns were connected to the main reservoir filled with DW, hydraulic head maintained constant and HC measured according to Darcy's law. When the HC measurement with the DW was over, the columns were separated and air dried (30 °C). These air-dried columns were then saturated with GSS and after maintaining the hydraulic head constant in the reservoir containing gypsum saturated solution (GSS), the HC measured.

Deep ploughing of the materials in columns was simulated by removing, drying (30 °C) and sieving the material <6 mm, the refilled soil columns were saturated with GSS, the HC was then measured with the same solution. The effluent was collected on a time flow basis and the volume recorded, and the HC for individual columns calculated.

RESULTS AND DISCUSSION

The volumes of the leachate were recorded up to 52 hours with DW (Table 2). Among the six layers leachate was only collected from upper three layers, the other three depths remaining blocked. The maximum initial value (~ 17 mm hr^{-1}) was obtained in the top layer (0-5 cm). The other two layers being <2 mm hr^{-1} were found to be blocked after 48 hours. These values clearly show a decreasing trend with depth. The reason is the higher amount of soluble salts (EC_e = 140 dS m^{-1} at 0-5 cm and 18 dS m^{-1} at 25-30 cm). With time the salts got diluted and the clays become more susceptible to dispersion and swelling.

Replacement of DW with GSS (0-5 cm samples) further reduced the HC value, while the rest of the columns remained blocked (Table 2). As clay did not appear in the leachate, this suggests that dispersion of clay particles and there movement in the conducting pores was the main mechanism in lowering HC by plugging soil pores. When DW was replaced by GSS, the soil columns of 5-10 and 25-30 cm depths remained blocked and no leachate was collected, whilst the HC was further reduced at 0-5 cm depth. This again suggests that swelling is not the main cause in lowering the HC values, otherwise the HC values should have been improved by the introduction of GSS. It is well known that swelling of the soil clay is a continuous and reversible process which decreases gradually with an increase in solution concentration. Whereas

Table 1. Physical and chemical characteristics of the soil profile*

Depth (cm)	EC_e ($dS\ m^{-1}$)	pHs	ESP	Class	Sand 2 mm-60 μm	Silt 60-2	Clay < 2	Coarse (C) clay 2-0.2	Fine (F) clay < 0.2	C/F	Textural class
					........%		........μm	........% of < 2 μm			
Khurrianwala soil series											
0-5	140.4	8.8	85	Saline-sodic	28	60	12	90	10	9.0	Sandy silt loam
5-10	46.4	8.6	73	"	21	65	14	80	20	4.0	"
25-30	18.3	8.4	56	"	18	55	27	76	24	3.2	Silty clay loam
45-50	23.3	9.7	84	"	17	59	24	67	33	2.0	"
65-70	15.9	9.7	83	"	15	59	26	69	31	2.2	"
125-130	11.2	8.6	46	"	14	60	26	68	32	2.1	"

* Soil samples were collected from a vast barren patch, on the left side of Lahore-Rawalpindi metalled road, opposite Chak Arainian, Grid reference: G 491766.

clay dispersion and deposition are irreversible processes and may cause the formation of an impermeable clay layer in the soil column.

Another reason for the reduction in the permeability with time may be that the soluble salts present were washed down in the leachate, and were reduced to a value in the soil where dispersion may be possible. Clay dispersion is very sensitive to low electrolyte concentration and, at given concentration, increased markedly at high ESP values (Oster *et al.,* 1980). The soil used also contained vermiculite clay minerals (Shahid, 1989), and in such soils the significance of dispersion in affecting soil permeability has been observed by Rhoades and Ingvalson (1969), who concluded that dispersion rather than swelling was the operative process reducing the permeability.

In the lower three layers no leachate was collected, which shows that the HC is undetectable. Appearance of clay can not therefore be expected in such conditions. The C/F ratio of clay reduced down the profile (Table 1), together with a dominance of smectites over the other clay minerals species (Shahid, 1989). Such minerals are capable of considerable expansion at moderate to high exchangeable sodium levels in the presence of low salt solutions. Hence they can impart rather substantial salinity-dependent changes in permeability. Even by the replacement of DW with GSS, no improvement in HC values was achieved, therefore, it is suggested that the blockage of the soil columns during both the treatments may be due to swelling and dispersion of the soil clays (Frenkel *et al.,* 1978).

Clay swelling operating in these columns may be due to "crystalline swelling" where it accompanies adsorption of the first two to three water layers by intercalation between the unit layers of phyllosilicate clays, and under normal conditions only montmorillonite and vermiculite exhibit such behaviour (Norish, 1954; Norish and Quirk, 1954). The other mechanism of swelling may be "osmotic swelling", and clay mineral swelling beyond the crystalline region has been considered to be osmotic in nature by a number of workers (El-Swaify and Henderson, 1967; Van Olphan, 1977).

depths) swelling being dominant. Appreciable changes in the HC values could only be obtained by combining gypsum addition with deep ploughing. It is, therefore, strongly recommended that for successful management of dense salt-affected soils deep ploughing like practices must be operated.

Table 2. Hydraulic conductivities of the Khurrianwala Soil Series

Depth (cm) (HC)	Distilled Water (DW) Initial (1 hr)	Distilled Water (DW) Final (52 hrs)	GSS Initial (1 hr)	GSS Final (180 hrs)	GSS + deep ploughing Initial (1hr)	GSS + deep ploughing Final (180 hrs)
	HC (mm hr^{-1})					
0-5	16.8 (MS)	15.4 (MS)	9.6 (MS)	9.8 (MS)	32 (M)	37 (M)
5-10	1.9 (S)*	blocked (VS)			18 (MS)	19 (MS)
25-30	1.4 (S)*	blocked (VS)			23 (M)	24 (M)
45-50	blocked (VS)				15 (MS)	17 (MS)
65-70	blocked (VS)				14 (MS)	16 (MS)
125-130	blocked (VS)				27 (M)	30 (M)

M = Moderate; MS = Moderately slow; S = Slow; VS = Very slow; * = Blocked after 48 hrs.

Further improvement of HC in these layers was assessed through deep ploughing + gypsum. The data (Table 2) show that the initial (1 hour) and final (180 hours) values of HC with deep ploughing + GSS ranged between 14-32 mm hr^{-1} and 16-37 mm hr^{-1}, respectively. These values fall under the moderately slow (MS) to moderate (M) categories of O'Neal (1952). Table 2 shows that deep ploughing + GSS enhanced the HC values considerably. It is, therefore, concluded that in the above three layers (0-5, 5-10 and 25-30 cm depths) dispersion, translocation and deposition of clay material in the conducting pores is the dominant mechanism of HC reduction, whereas in the lower three layers (45-50, 65-70 and 125-130 cm

REFERENCES

Day, P.R. 1965. Particle fractionation and particle-size analysis. In: "Methods of Soil Analysis". C.A. Black (ed.). Am. Soc. Agron. WI, USA. p. 545-566.

El-Swaify, S.A. and D.W. Henderson. 1967. Water retention by osmotic swelling of certain colloidal clays with varying ionic composition. J. Soil Sci. 18: 223-232.

Felhendler, R., I. Shainberg and H. Frenkel. 1974. Dispersion and hydraulic conductivity of soils in mixed solution. Trans. 10th Int. Congr. Soil Sci. Moscow, Vol. 1, Nauka, Moscow, p. 103-112.

Frenkel, H., J.O. Geortzen and J.D. Rhoades. 1978. Effects of clay type and content, exchangeable sodium percentage and electrolyte concentration on clay dispersion and soil hydraulic conductivity. Soil Sci. Soc. Am. J. 42: 32-39.

Hodgson, J.M. 1976. Soil Survey Field Handbook. Describing and sampling soil profiles. Soil Survey Tech. Monogr. No. 5, UK.

Klute, A. 1965. Laboratory measurement of hydraulic conductivity of saturated soil. In: Methods of Soil Analysis, C.A. Black (ed.), Ch. 13, p. 210-221.

McNeal, B.L., D.A. Layfield, W.A. Norvell and J.D. Rhoades. 1968. Factors influencing hydraulic conductivity of soils in the presence of mixed salt solution. Soil Sci. Soc. Am. J. 32: 187-190.

Norrish, K. 1954. Manner of swelling of montmorillonite. Nature, 173: 255-257.

Norrish, K. and J.P. Quirk. 1954. Crystalline swelling of motmorillonite. Nature, 173: 255-256.

O'Neal, A.M. 1952. A key for evaluating soil permeability by means of certain field clues. Soil Sci. Soc. Am. Proc. 16: 312-315.

Oster, J.D., I. Shainberg and J.D. Wood. 1980. Flocculation value and structure of Na/Ca montmorillonite and illite suspensions. Soil Sci. Soc. Am. J. 44: 955-959.

Page, A.L., R.H. Miller and D.R. Keeney. 1982. Methods of Soil Analysis. Part 2. Am. Soc. Agron. Mongr. No. 9. Madison, WI, USA. pp. 169-238.

Rhoades, J.D. and R.D. Ingvalson. 1969. Macroscopic swelling and hydraulic conductivity properties of four vermiculitic soils. Soil Sci. Soc. Am. Proc. 33: 364-369.

Richards, L.A. (ed.). 1954. Diagnosis and Improvement of Saline and Alkali Soils. USDA Handb. 60. Washington, DC.

Shahid, S.A. 1989. Clay, silt and sand mineralogical investigations of soil profiles. Ph.D. Thesis, Univ. Wales, Bangor, Gwynedd, UK. pp: 111-140.

Shainberg, I., J.D. Rhoades and R.J. Prather. 1981 a. Effect of low electrolyte concentration on clay dispersion and hydraulic conductivity of a sodic soil. Soil Sci. Soc. Am. J. 45: 273-277.

Shainberg, I,, J.D. Rhoades, D. Suarez and R.J. Prather. 1981 b. Effect of mineral weathering on clay dispersion and hydraulic conductivity of sodic soils. Soil Sci. Soc. Am. J. 45: 287-291.

Van Olphen, H. 1977. An introduction to clay colloidal chemistry. 2nd ed. Wiley, New York. pp: 1-301.

Yousaf, M., O.M. Ali and J.D. Rhoades. 1987. Dispersion of clay from some salt-affected arid land soil aggregates. Soil Sci. Soc. Am. J. 51: 920-924.