Caspian J. Env. Sci. 2005, Vol. 3 No.1 pp. 9~14
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CJES
Caspian Journal of Environmental Sciences

[Research]

Impact of Distillery Effluent and Salts on Hydraulic Conductivity of a Sandy Loam Soil

S. Chandra, H.C. Joshi and H. Pathak*
Division of Environmental Sciences, Indian Agricultural Research Institute, New Delhi 110 012, India.
**Institut fur Meteorology und Klimaforschung, Kreuzeckbahnstr 19, 82467, Garmisch-Partenkirchen, Germany. Corresponding Author's E-mail: hpathak_cass@yahoo.com*

ABSTRACT

Irrigation with distillery effluent, besides influencing crop yield, may have considerable impact on physical properties of soil because of its high salt and organic carbon contents. This experimental study was conducted to evaluate the effect of distillery effluent on hydraulic conductivity of a sandy loam alluvial soil and compare the effect of inorganic salts of potassium (K) with that of distillery effluent on hydraulic conductivity of soil. The treatments consisted of 4 sources of K: potassium chloride, potassium sulphate, post methantion distillery effluent (PME) and oxidized PME (PME minus organic carbon) at 4 levels equivalent to 10, 20, 40 and 100% of the K concentration in the PME. There were 4 replications for each treatment. Soils, collected from the upper 15 cm of a farm were crushed, passed through a 2-mm sieve and packed in 6.5 cm diameter and 50 cm long columns. Each of the solutions was applied 4 times at the interval of 20 days to the soil column, which were subsequently flushed with distilled water and saturated hydraulic conductivity of soil was measured using the constant head technique. Application of PME and salts increased the hydraulic conductivity of soil to 3 to 4 fold as compared to that of the untreated soil. With the increasing levels of salt concentration, the rate of increase in hydraulic conductivity initially decreased, but at 100% salt level soil hydraulic conductivity increased sharply. The oxidized PME, which contained only the inorganic salts present in the PME, had highest hydraulic conductivity at 100% salt level followed by PME and inorganic salts. The exchangeable K content of soil (x) and hydraulic conductivity (y) showed a polynomial relationship ($y = 15.28 - 1.61x + 0.05x^2$). The study showed that application of PME has significant impacts on soil hydraulic conductivity suggesting that impact assessment of PME application on physical properties of soil be recommended to find an optimum application rate before the practice is adopted.

Keywords: Exchangeable potassium, infiltration, post methanation distillery effluent, potassium chloride, potassium sulphate, soil salinity

INTRODUCTION

Distilleries producing alcohol from molasses, a by-product of sugar industry, are considered among the most polluting agro-based industries. The effluent generated by the distilleries contains very high (50000 mg L^{-1}) biochemical oxygen demand (BOD). Therefore, the effluent is subjected to the process of biomethanation to reduce the BOD to less than (or approximately) 5000 mg L^{-1} (Joshi *et al.* 1996). The post methanation distillery effluent (PME) is finally disposed off on land. However, the PME poses a problem for disposal because of its high organic and salt load. The point is that the indiscriminant application of effluent or wastewater to arable lands without assessing its impact on soil health may prove hazardous for both environment and agriculture. The major risks associated with irrigation with PME wastewater are degradation of soil health (e.g. degradation of aggregate stability and hydraulic conductivity, surface sealing enhancing runoff, soil erosion, soil compaction and a decrease in soil aeration). However, the PME effluent is a rich source of nutrient and is used for irrigation at many places in the world (Joshi *et al.* 1996). Studies have been conducted on fertilizer value of PME (Pathak *et al.* 1999) and mineralization of carbon in soil irrigated with PME (Chandra *et al.* 2002). Its effect on soil physical properties, however, has not been studied.

Hydraulic conductivity is an important property that determines soil health. Poor hydraulic conductivity is viewed as an agronomic problem (e.g., increased soil salinity, crop water stress and poor soil aeration) with severe economic conesquences. A major concern in irrigated agriculture is the maintenance of sufficiently high soil permeability for salinity control and for the reclamation of salt-affected soils. In addition to its dependence on other factors, soil hydraulic conductivity depends on the salt concentration of the soil (McNeal and Coleman, 1966).

Potassium salts, which may occur or be applied to soils in various operations, have significant influence on soil hydraulic conductivity. Levy and Vander Watt (1990) observed that increasing amount of K in the exchangeable phase of soil decreased hydraulic conductivity of three South African soils. They also found that relative to Ca and Na, exchangeable K had an intermediate effect on the hydraulic conductivity of the soils. Singh (1992) reported that infiltration rate decreased from 4.34 to 2.16 cm hr^{-1} with increase of distillery effluent level. On the contrary Devarajan *et al.* (1993) found significant improvement in the infiltration rate of the soils with distillery effluent irrigation.

The effect of salts present in the distillery effluent on soil property may not be similar to that of the inorganic salts due to the presence of dissolved organic matter, which may have the positive impact in stabilizing the soil aggregates and improving hydraulic conductivity. Goldberg *et al.* (1988) observed that dissolved organic matter in soils acted as cementing agent that improves aggregate stability. In the field experiment Joshi *et al.* (2000) observed that there is an increase in hydraulic conductivity on irrigation with distillery effluent in comparison to fresh water. The objectives of the study were to (1) evaluate the effect of distillery effluent with and without its organic C component on hydraulic conductivity of soil, and (2) compare the effect of inorganic salts on hydraulic conductivity of soil with that from distillery effluent.

MATERIALS AND METHODS

For the measurement of soil hydraulic conductivity as influenced by various potassium salts a laboratory experiment was conducted in the Division of Environmental Sciences, Indian Agricultural Research Institute, New Delhi, India.

Soil

Soil samples were collected from upper 15 cm of an alluvial soil at the Indian Agricultural Research Institute farm. The alluvial soil was *Typic Ustochrept*, sandy loam in texture, dark yellowish brown (10YR 5/4 D) in colour, moderate angular blocky in structure, slightly firm and slightly sticky with a smooth boundary. The entire volume of soil was thoroughly mixed and allowed to air dry. The soils materials were then crushed and sieved through a 2 mm screen. A representative sample was drawn for analyses using standard methods (Page *et al.* 1982). Selected properties of the soil are presented in Table 1.

Post Methanation Distillery Effluent

Post methanation distillery effluent was obtained from the biomethanation unit of the Shamli Distillery and Chemical Works, Shamli, Uttar Pradesh, India. The physico-chemical composition of the effluent was analyzed following the methods given by APHA (1980). The effluent had pH 8.8, EC 15.9 dS m^{-1}, organic C 15.0%, total N 0.02%, total K 3.76 g L^{-1}, Ca 1.2 g L^{-1}, Mg 0.62 g L^{-1}, Na 0.53 g L^{-1} chloride 2.0 g L^{-1} and sulphate 0.6 g L^{-1}.

Table 1. Physico-chemical properties of experimental soil

Properties	Values
pH (1:2 soil water)	8.6
EC (1:2 soil water) (dS m^{-1})	0.4
Organic carbon (%)	0.34
Total nitrogen (%)	0.04
Cation exchange capacity (cmol^{+} kg^{-1})	9.2
Water soluble K (mg kg^{-1})	60
Ammonium acetate extractable K (mg kg^{-1})	151
Total K (%)	2.0
Sand (%)	78.0
Silt (%)	14.0
Clay (%)	8.0
Texture	Sandy Loam
Bulk density (g cm^{-3})	1.43
Hydraulic conductivity (cm hr^{-1})	1.75
Saturation water content (cm^{3} /cm$^{3)}$	0.35
Porosity (%)	36.0

Treatments

The treatments consisted of 4 sources of K: 1) potassium chloride (KCl, chemical grade), 2) potassium sulphate (K_2SO_4, chemical grade), 3) oxidized PME (PME minus organic carbon, which was removed by oxidizing with 30% hydrogen peroxide solution and 4) PME, with 4 levels. In addition to the original

Table 2. Concentration of K (mg L^{-1}) added to the soil columns with different levels of potassium through different sources and the resultant electrical conductivity of the soil (dS m^{-1})

Treatments	L1[a]		L2		L3		L4	
	K[b]	EC[c]	K	EC	K	EC	K	EC
KCl	376	1.3	752	2.6	1504	5.1	3760	11.4
K_2SO_4	376	1.3	752	2.6	1504	4.6	3760	10.0
Oxidized PME [d]	376	1.3	752	2.5	1504	4.9	3760	10.6
PME	376	2.0	752	3.7	1504	7.9	3760	15.9
Untreated soil	10	0.8						

[a] L1, L2, L3 and L4 represent K levels equivalent to 10, 20, 40 and 100% of K present in post methanation distillery effluent (PME).

[b] Potassium added (mg L^{-1}) to the column with PME.

[c] Electrical conductivity (dS m^{-1}) of soil (1:1 soil water) after adding different salts, oxidized PME and PME

[d] Oxidized PME is PME oxidized with 30% H_2O_2

PME (K concentration of 3760 mg L^{-1}), three levels of K concentrations (376, 752, and 1504 mg K L^{-1}) were obtained by mixing appropriate amount of PME effluent with distilled water. These solution treatments represented 10% (L1), 20% (L2), 40% (L3) and 100% (L4) of the actual concentration of K in the PME solution. There were 4 replications for each treatment. Since distillery effluent is rich in K, KCl and K_2SO_4, which are common K fertilizers, were chosen in the study. Amounts of K added to the soil columns through different sources and the resultant electrical conductivity of the soil are given in Table 2.

The soil columns (6.5 cm internal diameter and 50 cm length) were filled with soil and compacted up to the bulk density equivalent to that in the field (1.43 g cm^{-3}). Water content of 4% (volume basis) was maintained in the soil to avoid dusting during the packing of the column. Weight of the moist soil used in packing of the column was calculated by using the formula: $M = \rho * (1+Pw) * V_s$, where M is mass of the moist soil, Pw is water content of the soil, ρ is desired bulk density, V_s is volume of the column ($V_s = \pi r^2 h$, where r is radius of the column and h is height up to which soil was to be filled). Fifteen g of glass wool was placed at the bottom of each column and the soil packing was done with the interval of 5 cm height each time. The soil in column was compressed with a piston and the crust formed at the surface of compression was broken with the help of plunger before adding the next soil of 5 cm height. After packing, the mass of each soil column was recorded.

The columns were treated with 6 cm solutions of different salts and PME 4 times at the interval of 20 days to add various doses of K (Table 2). The amount of 6 cm water was equivalent to irrigation commonly applied by the farmers for irrigating their crops. At the end of these treatments, the columns were leached with fresh water till the EC of input water and output water became same suggesting that no more salt was leaching from soil. The leachate was collected and analyzed for EC and K content. The soil samples were analyzed for water soluble and neutral normal ammonium acetate extractable K contents using the method given by Knudsen *et al.* (1982). The exchangeable K was estimated by the difference of the ammonium acetate extractable K and water-soluble K. Saturated hydraulic conductivity of soil was measured by the constant head (5 cm) method (Klute and Dirksen, 1986).

RESULTS AND DISCUSSION

Application of K through different salts and PME increased the hydraulic conductivity of soil (Table 3). At level L1 (10% of K present in PME) all the treatments showed 3 to 4 fold increase in the hydraulic conductivity compared to the untreated soil. At other levels of salt (L2, L3 and L4) the conductivity increased by a factor of 1.5 or more compared to the untreated soil. The rate of increase in hydraulic conductivity was different among various treatments but the increase in hydraulic conductivity was highest with the PME treatment.

As the levels of salt concentration increased from level L1, the soil hydraulic conductivity decreased up to level L3. At level L2, for example, where the salt concentration is twice as compared to level L1, the hydraulic conductivity decreased by

50-75% in different treatments. All the sources of K showed similar trends but the magnitude of decrease from level L1 to L3 was the sharpest in case of K_2SO_4 treated soil. In case of PME treated soil the rate of decrease was slower compared to other treatments indicating role of organic matter present in the effluent. The soil treated with oxidized PME also showed relatively lower decrease in hydraulic conductivity indicating role of other salts accompanying K in the inorganic effluent. At level 4 (L4), however, there were 4 to 8 times increase in the soil hydraulic conductivity. The oxidized effluent, which contained the inorganic salts present in the PME, had highest hydraulic conductivity at this level (L4) followed by distillery effluent and inorganic salts. The hydraulic conductivity of soil with KCl and K_2SO_4 were similar suggesting that inorganic salts behave similarly in influencing the hydraulic conductivity. The highest conductivity with oxidized PME treatment was due to the presence of other salts of Ca and Mg in addition to that of K.

The exchangeable K content of soil increased with the level of K application but the sources of K did not have any significant influence on soil exchangeable K (Table 4). The exchangeable K content of soil (x) and hydraulic conductivity (y) showed a polynomial relationship: $Y=15.28-1.61X+0.05X^2$ (Fig. 1). Levy and Vander Watt (1990) reported that increasing the amount of K in the exchangeable phase resulted in decrease in the hydraulic conductivity, as well as the infiltration rate of soil. They suggested that these phenomena are related to the clay mineralogy of the soils, being smallest in the kaolinitic soils where the iron oxides could have had some overriding stabilizing effect, and biggest in the illitic soil. Similar results have been found by Quirk and Schofield (1955) that exchangeable K and exchangeable Na had the deleterious effect on soil hydraulic conductivity. On the contrary, Cecconi *et al.* (1963), Ravina (1973) and Chen *et al.* (1983) reported that soils with higher exchangeable K had higher hydraulic conductivity of soils because of larger aggregates and greater aggregate stability, which had favorable effects on soil permeability. Wiegand *et al.* (1966) found infiltration rates of saline soil to be several times higher than that of a non-saline, light textured soil. All the earlier studies did not

Table 3. Hydraulic conductivity of soil with different levels of potassium through different sources

Treatments	Hydraulic conductivity (cm hr^{-1})				
	L1[a]	L2	L3	L4	Mean
KCl	6.84	4.76	2.35	8.01	5.49
K_2SO_4	7.85	3.48	1.95	8.08	5.34
Oxidized PME	7.86	5.10	2.40	16.96	8.08
PME	8.00	6.37	2.96	13.65	7.75
Mean	7.64	4.93	2.42	11.68	
Untreated soil	1.75				

CD ($P<0.05$): Sources of K = 1.38, Levels of K = 1.38, Source X Level = 1.96

[a]L1, L2, L3 and L4 represent K levels equivalent to 10, 20, 40 and 100% of K present in post methanation distillery effluent (PME).

Table 4. Exchangeable K content of soil with different levels of potassium through different sources

Treatments	Exchangeable K (%)				
	L1[a]	L2	L3	L4	Mean
KCl	6.08	10.17	20.50	28.72	16.37
K_2SO_4	6.07	9.03	17.24	24.00	14.09
Oxidized PME	5.80	8.75	12.64	24.64	12.96
PME	7.07	10.05	19.57	27.53	16.06
Mean	6.26	9.50	17.49	26.22	
Untreated soil	2.66				

CD ($P<0.05$): Sources of K = NS, Levels of K = 3.18, Source X Level = NS

[a]L1, L2, L3 and L4 represent K levels equivalent to 10, 20, 40 and 100% of K present in post methanation distillery effluent (PME)

include the whole range of exchangeable K in soil and as a result could not encounter the complete picture of the influence of soil exchangeable K on hydraulic conductivity. The present study, while considering a very wide range of salt addition showed that hydraulic conductivity decreases up to 40% exchangeable K, and increases thereafter following the polynomial relationship as given above. Mitchell and Donovan (1991) also reported that soil permeability and leaching may increase when saline drainage water is used in crop production.

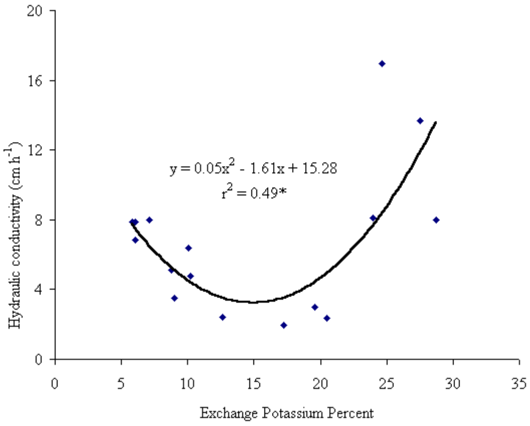

Fig. 1 Relationship between exchange potassium percent and hydraulic conductivity of soil. The exchange potassium percent is based on CEC

The use of soil as a medium for the treatment and disposal of industrial wastewater is becoming increasingly common. The increasing application of wastewater in agricultural fields may serve as a viable method of disposing the wastewater and sustaining agriculture production in non-irrigated areas having shortage of fresh water for irrigation. However, inappropriate use of wastewater in arable land may prove hazardous for both environment and agriculture because this water differs from its fresh water of origin by a higher electrolyte concentration and the presence of dissolved organic carbon and suspended solids. The study showed that application of distillery wastewater increases the hydraulic conductivity initially, decreased with higher dose and increases sharply thereafter suggesting that impact assessment of wastewater application in agriculture on physical properties of soil be recommended to find an optimum rate of irrigation before the practice is adopted.

ACKNOWLEDGEMENT

We thank the Dean and Director, Indian Agricultural Research Institute, New Delhi for granting financial assistance to carry out the study.

REFERENCES

APHA (1980) Standard Methods for the Examination of Water and Wastewater, 15th Edition. (APHA, AWWA, WPCF), XIVII, 1134 pp.

Cecconi, S., Salazsand, A. and Martelli, M. (1963) The effect of different cations on the structural stability of some soils. *Agro Chimica* **7,** 185-204.

Chandra, S., Joshi, H.C., Pathak, H., Jain, M.C. and Kalra, N. (2002) Effect of potassium salts and distillery effluent on carbon mineralization. *Bioresource Tech.* **83,** 255-257.

Chen, Y., Banin, A. and Borochovitch, A. (1983) Effect of potassium on soil structure in relation to hydraulic conductivity. *Geoderma* **30,** 135-147.

Devarajan, L., Rajannan, G. S., Ramnathan, G. and Oblisami, G. (1993) Sugarcane cultivation with distillery effluent. *SISSTA Sugar J.* **20,** 23-25.

Goldberg, S., Suarez, D. L. and Glaubig, R. A. (1988) Factors affecting clay dispersion and aggregate stability of acid-zone soils. *Soil Sci.* **164,** 317-325.

Joshi, H. C., Kalra, N., Choudhary, R., Pathak, H., Chaudhary, A. and Singh, N. N. (1996) Agrocycling – A pollution control strategy for Distilleries in India. *The Botanica* **46,** 170-176.

Joshi, H. C., Pathak, H., Chaudhary, A., Joshi, T. P., Phogat, V.K. and Kalra, N. (2000) Changes in soil properties with distillery effluent irrigation. *J. Environ. Res.* **6,** 153-162.

Klute, A. and Dirksen, C. (1986) Hydraulic conductivity and diffusivity: Laboratory Methods. In: Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods. (Ed: A. Klute) Agr. Monogr. 9.ASA and SSSA, Madison, WI, USA, 687-734.

Knudsen, D., Peterson, G. A. and Pratt, P. F. (1982) Lithium, Sodium, and Potassium: In: Methods of soil analysis. Part 2, Chemical and microbiological properties, (Eds. Page, A.L., Miller, R.H. and Keeney, D.R.), 2nd edition, Agronomy No. 9, ASA-SSSA, Madison, WI, USA, 225-246.

Levy, G. J. and Vander Watt, H. V. H. (1990) Effect of exchangeable potassium on the hydraulic conductivity and infiltration rate of some South African soils. *J. Soil Sci.* **149,** 69-77.

McNeal, B. L. and Coleman, N. T. (1966) Effect of solution composition on soil hydraulic conductivity. *Soil Sci. Soc. Am. Proc.* **20,** 308-312.

Mitchell, A. R. and Donovan, T. J. (1991) Field infiltration of a salt-loaded soil: evidence a permeability hystersis. Soil Sci. Soc. Am. J. 55: 706-710.

Page, A. L., Miller, R. H. and Keeney, D. R. (1982) Methods of Soil Analysis. Part 2, Chemical and Microbiological Properties, 2nd edition, Agronomy No. 9, ASA-SSSA, Madison, WI, USA.

Pathak, H., Joshi, H. C., Chaudhary, A., Chaudhary, R., Kalra, N. and Dwivedi, M. K. (1999) Soil amendment with distillery effluent for wheat and rice cultivation. *Water, Air Soil Pollut.* **113,** 133-140.

Quirk, J. P. and Schofield, R. K. (1955) The effect of electrolyte concentration on soil permeability. *J. Soil Sci.* **6,** 163-178.

Ravina, T. (1973) The mechanical and physical behaviour of Ca-clay soil and K-clay in soil. *Ecological Studies* **4,** 131-140.

Singh, Y. (1992) Report on utilisation of distillery waste from VAM Organic Chemicals Gajrauala in Agriculture. G.B. Pant University of Agriculture and Technolgy, Pantnagar, India, pp 150.

Wiegand, C. L., Lyles, L. and Carter, D. L. (1966) Interspersed salt-affected and unaffected dryland soils of the lower Rio Grande Valley: II Occurrence of salinity in relation to infiltration rates and profile characteristics. *Soil Sci. Soc. Am. Proc.* **30,** 106-110.

(Received: Jan. 26, Accepted Mar. 18, 2005)