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Soil Infiltration in Relation to Physico-Chemical Properties under Different Landforms in Coastal West Bengal

Shishir Raut[1], D Burman[2], SK Sarangi[3], TD Lama[4]

Author's Affiliation: [1]Scientist SS, [2,4]Principal Scientist, Department of Soil Science, [3]Principal Scientist, Department of Agronomy, ICAR-Central Soil Salinity Research Institute, Regional Research Station, Canning Town, West Bengal 743329, India.

Corresponding Author: Shishir Raut, Scientist SS, Department of Soil Science, Department of Agronomy, ICAR-Central Soil Salinity Research Institute, Regional Research Station, Canning Town, West Bengal 743329, India.

E-mail: shi_cssri21@yahoo.com

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Abstract

Soil infiltration in relation to organic matter and its humic components namely, humic acid and fulvic acid for different soils coming under different landforms namely, cultivated deltaic, non cultivated deltaic, depressed land and mudflats were analyzed for a coastal Block (Gosaba) of West Bengal. Results showed that organic carbon content of all soils were medium (0.54%) to high (1.28%), salinity was low to high (3.6-13.7dS/m). The steady state cumulative infiltration of cultivated deltaic soils were higher than depressed low soils may be because of higher fulvic acid content in deltaic soil (0.14-0.15%) than depressed soils (0.09-0.10%). The non cultivated deltaic soil also showed higher fulvic acid content (0.11-0.13%) than depressed soil (0.09-0.10%) The humic acid: fulvic acid ratio decreased with soil depth. The relationships between steady state cumulative infiltration and EC, pH, clay, porosity and humic acid were significant (r = -0.79*, -0.75*, -0.82*, -0.90** and -0.93**, respectively), exponential and negative. With increase in soil salinity, in general there was a decrease in organic matter content of all soils.

Keywords: Index Terms; Humic acid; Landforms; Salinity; Sorptivity.

Introduction

Infiltration is one of the major components of the hydrologic cycle. Water that falls as precipitation may run over land eventually reaching streams, lakes, rivers and oceans or infiltrate through the soil surface, into the soil profile. Water that runs off over land causes erosion, flooding and degradation of water quality. Infiltration, on the other hand, constitutes the sole source of water to sustain the growth of vegetation, is filtered by the soil which removes many contaminants through physical, chemical and biological processes, and replenishes the ground water supply to wells, springs and streams. Infiltration is a primal factor in soil hydrology because it determines the amount of runoff during a rainstorm and the amount of water stored in the root zone and ground water recharge.[1] Infiltration is affected by the inherent properties of the soil such as soil texture and soil structure, which in turn affect the pore space and matric and gravitational forces, and initial moisture condition, the rainfall pattern, and land use and soil management practices.[2] Soil textural characteristics, specifically the percentage clay and sand ,affect infiltration, because they determine whether infiltration rate is dominated by gravity forces or capillarity forces, under a given rainfall intensity. Soil structure and its surrogate, soil aggregates, influences infiltration characteristics and have been used as a good indicator of changes in soil physical and biological properties. Significant relationships exist between steady infiltration rates and soil organic matter, bulk density, and total porosity. The infiltration rates change due to soil hydraulic properties, porosity, soil organic matter and bulk density and different land use practices.[3]

The ability of a soil to absorb water during infiltration is called sorptivity. Many models have been developed to describe liquid infiltration in a porous material, including those by Parlange and co-workers.[4-9] These models predict the time-rate of infiltration and the cumulative volume of infiltration based on parameters like the sorptivity[10], which quantifies the effect of capillarity on a liquid's movement in a material.

Theoretically, it had been established that in absence of gravity effect, the amount of water absorbed during infiltration is proportional to the square root of time (t) when water is allowed to infiltrate into a horizontal column of porous material the surface of which is maintained at a constant moisture content[11] i.e., $I = St^{½}$ where S is a constant and is called sorptivity, I is cumulative infiltration and t is time.

Intensification of agriculture with adoption of multiple cropping systems and energy intensive cultivation practices, especially excessive tillage and imbalanced use of chemical fertilizers led to further deterioration of soil organic matter (SOM). Soil infiltration and sorptivity are also affected by different components of SOM like humic acid, fulvic acid and humin. The status of soil organic matter of tropical countries like India is generally much below the threshold levels.[12]

For an efficient management of SOM, it is necessary to study the influence of agricultural impact, soil salinity and cropping sequence on organic matter availability.[13] The objectives of this study were: i) to study soil infiltration and physico-chemical characteristics as influenced by organic matter under different landforms and ii) to study different fractions of organic matter in relation to cropping sequence in different landforms.

Materials and Methods

Soil samples were collected for the rabi season (February-March) of 2017 from three different depths (0-20, 20-40, 40-60 cm) from three different villages of Gosaba Block (Lat. 22o 09′-22o10′ N; Long. 88o47′-88o48′ E) of South 24 Parganas district of West Bengal coming under three different landforms namely, cultivated deltaic (CD), mudflat (MUD) and depressed lowland (DL) for the first season. The samples were also collected from non cultivated deltaic (NCD), MUD and DL soils for the second season (February-March, 2018). The humic acid and fulvic acid fractions of organic matter were separated following the procedures of Kononova.[14]

The horizontal infiltration study was carried out in the laboratory using plexiglass columns. The columns were filled as uniformly as possible with soil sample at a bulk density of 1.2 Mg m-3. Columns were placed horizontally on a wooden stand and water was introduced to the inlet end from marriotte tube from the diffusivity measuring cylinder. Water entering the column was measured volumetrically. After completion of the infiltration, the columns were sectioned into one cm segments and water content was determined gravimetrically. From these, soil water diffusivity, $D(\theta)$ was calculated 15 by using eqn 1:$D(\theta)= -1/2t.dx/d\theta +\int x d\theta$ ------(1) where, t is time; x is distance; the definite integral is solved between initial wetness (θi) and final wetness (θo).

Sorptivity was determined by the following equation (eqn 2): $S= (\theta o-\theta i)(\check{D}/\pi)1/2$ --------(2) where, Ď is weighted mean diffusivity, θi is initial soil water content, θo is saturated wetness and t is time. The weighted mean diffusivity was calculated according to the eqn 3 as given below 16:

$\check{D} =1.66/(\theta 0- \theta i)5/3 + \int D(\theta)(\theta 0-\theta i)\ 2/3\ d\theta$ -----(3)

Where, Ď is weighted mean diffusivity, θi is initial moisture content, $\theta 0$ is saturated moisture content, $D(\theta)$ is soil-water diffusivity. Relationship between steady state cumulative infiltration and other soil parameters were also determined. The soil physic-chemical properties like porosity, organic carbon, salinity, pH etc. were determined by conventional techniques.

Results and Discussion

Physicochemical parameters, infiltration characteristics and sorptivities.

The cultivated deltaic (CD) soil observed highest steady state cumulative infiltration (5.0 cm) followed by mudflat (MUD) soil (3.5 cm) and depressed low land soil (DL) soil (1.9 cm) (Figure 1). This result can be verified from the slope of the cumulative infiltration and time curves (Figure 2). In 50 minutes time only 1.2 cm water infiltrated in DL soil. For the same period 3.0 cm water infiltrated in CD soil. Infiltration in MUD soil was medium (2.1 cm).

The NCD soil was having relatively higher cumulative infiltration as compared to CD soil may be because of its coarser texture (Scl) (Figure 1 and 3). The seasonal variation of infiltration in MUD soil and DL soils was low (Figure 1 and 3). The texture of Mud flat (MUD) and depressed low (DL) soils were sandy clay loam to clay, with a clay content of 38-46 % in the surface layer (Table 1). Clay content in cultivated deltaic soil (CD) was 30-35 % and was clay loam in texture. In the 20-40 cm and 40-60 cm soil layer for DL soils clay content did not differ much (42-44 %, clayey).

All the soils were medium to high in organic C content (0.54-1.28 %). The highest porosity or saturation water content was found in DL soil (0.63-0.64 $cm^3\ cm^{-3}$) and the lowest was in CD soil (0.57-0.61 $cm^3\ cm^{-3}$). The CD and MUD surface soils were slightly acidic (pH 4.8 to 6.0). The EC values of CD soils were low for all depths (3.1 to 4.9 dS /m); other two soils were having higher EC values (5.2-13.7 dS/m) (Table 1). The NCD soils were sandy clay loam to clay loam in texture with clay content of 24-63% with relatively high organic carbon (0.51-1.20%) (Table 2).

The EC values of soils collected from different landforms for the second season was lower (2.0-2.1 dS / m in NCD soil, 2.0-5.8 dS /m in MUD soil, 10-11.2 dS / m in DL soil) than those of 1st season. The saturated water content was highest (0.63-0.68 $m^3\ m^{-3}$) in DL soil and relatively low (0.63-0.64 $m^3\ m^{-3}$) in MUD soil. In this study, organic carbon percentages for all landforms decreased with soil depth (Table 1). The organic carbon content of MUD soils (0.54-0.64%) were less than that of DL (0.54-0.86%) and CD (0.76-1.28%) soils (1st season). The saturation moisture content (porosity) of different layer did not vary much because of their similar textural content (Table 1 and 2).

Similarly, the high porosity of DL soils were associated with high clay content for all the three layers. EC values for CD and NCD soils were low (<5dS / m and < 2.1 dS / m, respectively) and high for DL and MUD soils (10.0-13.7 dS / m), which decreased slightly with soil depth (Table 1 and 2). This might be due to accumulation of salts at the surface soils.

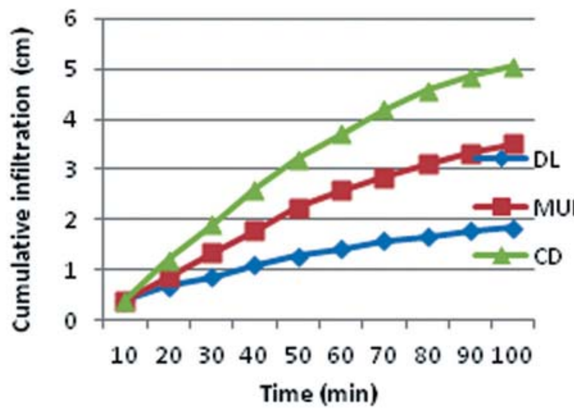

Fig. 1: Cumulative infiltration and time relationship (1st season).

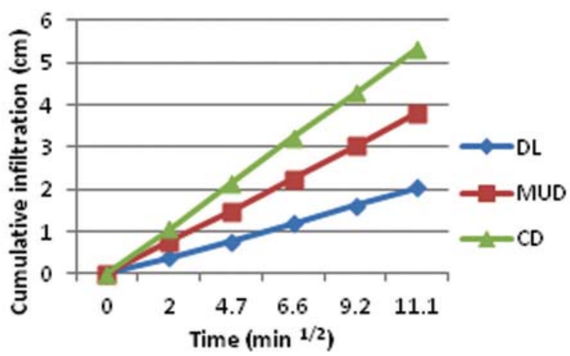

Fig. 2: Cumulative infiltration as a function of square root of time (1st season).

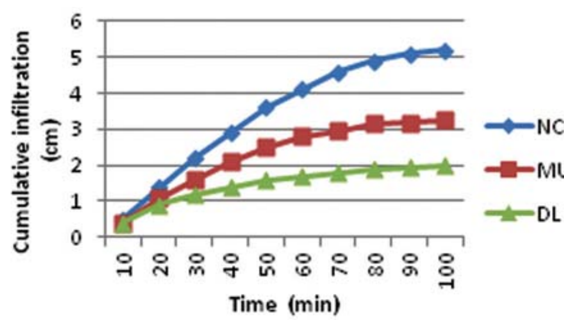

Fig. 3: Cumulative infiltration and time relationship (2nd season).

Water content of air dried soil before initiation of infiltration ($ø_i$), final water content ($ø_s$) and gain in water content are presented in Table 3 and 4. The water content in soils before infiltration varied from 0.01-0.02 $cm^3\ cm^{-3}$ in MUD and 0.02-0.03 $cm^3\ cm^{-3}$ in DL soils, whereas values were 0.02-0.04 $cm^3\ cm^{-3}$ in CD soils. The values were 0.02-0.04 $cm^3\ cm^{-3}$ in NCD soils. Sorptivity was highest.

Table 1: Physico-Chemical characteristics of Gosaba soi (1st season).

Name of Soil	Particle size (%)			Tex Class	Org C	pH	EC_2 (dS/m)	θ_s ($m^3 m^{-3}$)
	S	Si	C					
0-20 cm								
CD	30	35	35	cl	1.28	4.8	4.9	0.57
MUD	34	20	46	C	0.54	6.0	5.2	0.60
DL	26	36	38	cl	0.86	7.8	13.7	0.63
20-40 cm								
CD	38	32	30	cl	1.20	5.0	3.6	0.58
MUD	44	20	26	Sacl	0.64	6.2	6.0	0.61
DL	20	38	42	C	0.54	7.2	13.7	0.64
40-60cm								
CD	32	34	34	cl	0.76	5.1	3.1	0.61
MUD	46	18	36	SaC	0.60	6.3	6.0	0.62
DL	28	28	44	C	0.60	7.6	11.0	0.64

Table 2: Physico-chemical Characteristics of Gosaba soil (2nd season).

Name of Soil	Particle Size (%)			Tex Class	Org C	pH	EC_2 (dS/m)	θ_s ($m^3 m^{-3}$)
	S	Si	C					
0-20 cm								
NCD	18	58	24	Scl	1.20	5.0	2.1	0.66
MUD	34	20	46	C	1.02	5.6	2.0	0.63
DL	30	23	47	C	0.62	7.4	11.2	0.67
20-40 cm								
NCD	24	48	28	cl	1.10	6.2	2.0	0.66
MUD	40	20	40	SiC	0.64	7.7	5.8	0.63
DL	18	34	48	C	0.54	7.6	10.0	0.63
40-60cm								
NCD	13	24	63	cl	0.51	5.9	2.0	0.63
MUD	32	24	44	SC	0.64	7.5	3.8	0.64
DL	24	16	50	C	0.50	7.4	11.0	0.68

S: sand, Si: Silt, C: clay, and l: loam; CD: cultivated deltaic, MUD: mudflat/mangrove, DL: depressed low land.

S: sand, Si: Silt, C: clay, and l: loam; NCD: non-cultivated deltaic, MUD: mudflat/mangrove, DL: depressed low land.

(2.2-2.5 mmmin-1/2) in CD soil, followed by 2.1-2.2 mmin-1/2 in MUD soil and 1.0-1.5 mmmin-1/2 in DL soils. The sorptivity values of NCD soils were higher (3.1-3.5 mmmin-1/2) than those of DL soils (1.0-1.1mmmin-1/2). Sorptivity values differ significantly for three different landforms for different depths (Table 3 and 4). The weighted mean diffusivity values are also given in tables. These results can also be verified from the slope of the cumulative infiltration versus square root of time relationship curves (Figure 2 and 4). The slopes of NCD (0.39) and CD soils (0.38) in the present study were higher than the MUD (0.27) and DL (0.14-0.16) soils (Table 3a).

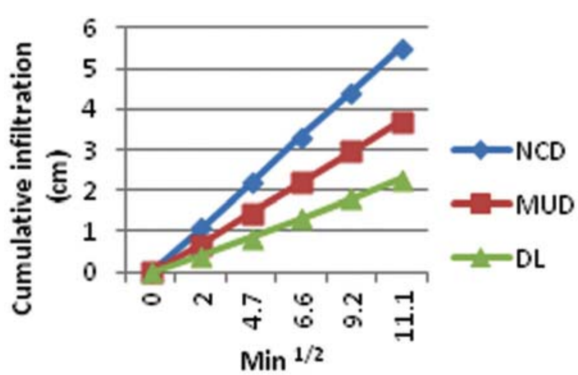

Fig. 4: Cumulative infiltration as a function of square root of time (2nd season).

Table 3: Water content of soil samples, gain in water content and sorptivity (1st season).

Name of Soil	θ_i	θ_s	$\theta_s - \theta_i$	Sorptivity (mmmin$^{-1/2}$)
0-20 cm				
CD	0.02	0.44	0.42	2.5 (2.0)*
MUD	0.02	0.38	0.36	2.1 (0.89)
DL	0.03	0.45	0.42	1.5 (0.83)
20-40cm				
CD	0.03	0.44	0.41	2.4 (1.9)
MUD	0.01	0.40	0.39	2.2 (0.90)
DL	0.03	0.46	0.43	1.0 (0.60)
40-60cm				
CD	0.04	0.45	0.41	2.2 (1.8)
MUD	0.01	0.42	0.41	2.1 (0.89)
DL	0.02	0.46	0.44	1.0 (0.65)

CD: cultivated deltaic, MUD: mudflat/mangrove, DL: depressed low land; θ_i : initial water content, θ_s: saturated water content, $\theta_s - \theta_i$: gain; $F_{2,6} > F_{tab(1\%)}$; CD = 1.1; T_1 = 7.1, T_2 = 6.4, T_3 = 3.5; ()* weighted mean diffusivity (cm^2/min).

Table 3a: Slope of cumulative infiltration and time curve for soils of different landforms.

Type of Landform	Slope	
	1st season	2nd season
CD/NCD	0.38	0.39
MUD	0.27	0.27
DL	0.14	0.16

CD/NCD: cultivated/non-cultivated deltaic, MUD: mudflat/mangrove, DL: depressed low land.

Table 4: Water content of soil samples, gain in water content and sorptivity (2nd season).

Name of Soil	θ_i	θ_s	$\theta_s - \theta_i$	Sorptivity (mmmin$^{-1/2}$)
0-20 cm				
NCD	0.02	0.40	0.38	3.5 (2.7)
MUD	0.02	0.36	0.34	2.5 (0.93)
DL	0.03	0.44	0.41	1.1 (0.62)
20-40cm				
NCD	0.04	0.41	0.37	3.3 (2.7)
MUD	0.03	0.36	0.33	2.3 (0.94)
DL	0.04	0.43	0.39	1.0 (0.60)
40-60cm				
NCD	0.04	0.41	0.37	3.1 (2.6)
MUD	0.03	0.41	0.38	2.1 (0.90)
DL	0.04	0.44	0.40	1.0 (0.61)

NCD: non-cultivated deltaic, MUD: mudflat/mangrove, DL: depressed low land; θ_i : initial water content, θ_s: saturated water content, $\theta_s - \theta_i$: gain; F 2,6> F tab (1%); CD = 1.0; T_1 = 9.9, T_2 = 6.9, T_3 = 3.1; ( )* weighted mean diffusivity (cm^2/min).

Table 5: Humic acid and fulvic acid content of Gosaba soil (1st season).

Soils	Total organic matter (%)	H.A. (%)	F.A. (%)	H.A. / F.A. Ratio
0-20 cm				
CD	2.21	0.10	0.15	0.7
MUD	0.93	0.15	0.13	1.2
DL	1.48	0.30	0.09	3.3
20-40 cm				
CD	2.07	0.08	0.15	0.5
MUD	1.10	0.15	0.14	1.1
DL	0.93	0.30	0.10	3.0
40-60 cm				
CD	1.31	0.06	0.14	0.4
MUD	1.03	0.16	0.15	1.1
DL	1.03	0.25	0.09	2.8

CD: cultivated deltaic, MUD: mudflat/mangrove, DL: depressed low land; H.A : Humic acid, F.A.: Fulvic acid.

Table 6: Humic acid and fulvic acid content of Gosaba soil (2nd season).

Name of Soil	Total organic matter (%)	H.A. (%)	F.A.(%)	H.A/F.A. ratio
0-20 cm				
NCD	2.1	0.08	0.12	0.7
MUD	1.8	0.18	0.11	1.7
DL	1.1	0.31	0.10	3.1
20-40cm				
NCD	1.9	0.08	0.13	0.6
MUD	1.1	0.16	0.10	1.6
DL	0.93	0.29	0.09	3.0
40-60cm				
NCD	0.88	0.07	0.11	0.5
MUD	1.1	0.14	0.09	1.5
DL	0.87	0.27	0.09	3.0

NCD: non-cultivated deltaic, MUD: mudflat/mangrove, DL: depressed low land; H.A : Humic acid, F.A.: Fulvic acid.

Table 7: Relation between Steady state cumulative infiltration (Is) and other parameters of soil.

Soil Separates (X)	Square of Correlation Coeff. (r^2)	Regression Equation
% Clay	0.77 *	Y=0.59+0.03X
% Clay + silt	0.76 *	Y=0.49+0.02X

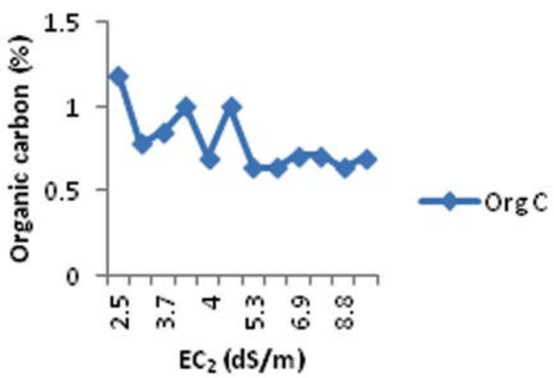

Fig. 5: Soil salinity and organic carbon relationship for soils of different landforms.

Humic acid and fulvic acid

The humic acid (H.A.) and fulvic acid (F.A.) fractions of organic matter in the present study are given in Table 5 and 6, respectively. The results showed that the fraction of H.A. was highest (0.30%) in DL soil and the fraction of F.A. was lowest (0.10%) in the surface layer of the same soil. On the other hand, the F.A. fraction was highest in CD soil (0.15%). MUD soils showed intermediate values (0.14%). The NCD soils were containing low H.A. (0.07-0.08%) and high F.A. (0.11-0.13%).

In the lower soil depths H.A. % was higher in the DL soils (0.25 to 0.30). The H.A./F.A. ratio decreased with depth (0.7 to 0.4 for CD and 3.3 to 2.8 for DL land soils) (Table 5).The high cumulative infiltration in CD soil may be associated with its high fulvic acid content and low humic acid content as compared to other soils (Table 5).[17,18]

The relationships between steady state cumulative infiltration and EC, pH, clay, porosity and humic acid were significant (r = -0.79*, -0.75*, -0.82*, -0.90**and -0.93**, respectively), exponential and negative (Table 7). These were in agreement with the findings of Singh and Kundu 19 for Odisha soils. Percentage fulvic acid was positively correlated (r=+0.78*) with steady state cumulative infiltration. Table 8 shows that the clay content and clay plus silt content were significantly positively correlated with the percentage of organic carbon (r2 = 0.77 and 0.76, respectively).

This may be because of the decrease in C mineralization with increase in finer sized particles. Or, in other words, pores of smaller sizes protect organic substrates against microbial decomposition in soils.[20] Humus is the major soil organic matter component making up 75-80% of the total organic matter. The humic acid fulvic acid ratio in the present study was 0.7, 1.2 and 3.3 in the surface layers of CD, MUD and DL soils, which decreased with soil depth (0.40, 1.1, & 2.8, respectively in 40-60 cm layer). These findings are in agreement of those of Weil.[21]

The humic acid and fulvic acid ratio also decreased with soil depth in case of NCD soils (0.70 to 0.60 and 0.50, respectively in 20-40 cm and 40-60 cm soil layers) (Table 6). In general, with increase in EC values, there was a decrease in organic carbon content. This may be attributed to the decrease in activity of organic matter sequestering organisms. The organic C % was high at EC values 3.7-4.3 (dS /m) may be because of addition of F.Y.M (Figure 5) in those fields.

Table 8: Relation between soil separates and organic carbon (Y).

Soil parameter	Correlation Coefficient (r)	Regression Equation
% Clay	-0.82*	$I_s = 20.8\ e^{-0.05x}$
EC (dS/m)	-0.79*	$I_s = 5.0\ e^{-0.07x}$
pH	-0.75*	$I_s = 11.9\ e^{-0.22x}$
Porosity (%)	-0.90**	$I_s = 42.6\ e^{-15.5x}$
H.A. (%)	-0.93**	$I_s = 6.3\ e^{-4.2x}$
F.A. (%)	+0.78*	$I_s = 0.99\ e^{9.2x}$

Conclusions

- Organic carbon content of all soils were medium (0.54%) to high (1.28%), salinity was low to high (3.6-13.7dS/m).
- The cultivated deltaic (CD) soil in the present study registered highest steady state cumulative infiltration (5.0 cm) followed by mudflat (MUD) soil (3.5 cm) and depressed low land soil (DL) soil (1.9 cm).
- The non cultivated deltaic soils also showed highest steady cumulative infiltration (5.2 cm) than other soils. Decline in water repellency of soil may be due to the presence of water soluble fulvic acid. The CD soils in the present study had higher fraction of fulvic acid (0.14-0.15%) for which these were more capable of infiltration. However, DL soils with greater fraction of insoluble humic

acid (0.25 – 0.30%) were water repellent and exhibited less cumulative infiltration. MUD soils showed intermediate humic acid and fulvic acid contents.

- In general, with increase in EC values, there was a decrease in organic carbon content of soils.

Conflicts of Interest

The authors declare no conflict of interest.

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