



Research Article

Influence of Soil Physicochemical Parameters and Humic Components of Organic Matter on Sorptivity Studied under Different Landforms in a Coastal Soil

SHISHIR RAUT*, D. BURMAN, U.K. MANDAL, S.K. SARANGI AND T.D. LAMA

Central Soil Salinity Research Institute, Regional Research Station, Canning Town, South 24 Parganas-743 329, West Bengal

ABSTRACT

Sorptivity was determined for soils coming under three different landforms, namely, non cultivated deltaic (NCD), mudflat / mangrove (MUD), and depressed low land (DL) from three different villages of Gosaba Block of West Bengal (India) covering approximately four square km area during two different seasons. The study was carried out in laboratory at room temperature in plexiglass columns. Physicochemical parameters like pH, EC, saturated moisture content, texture, organic C were also determined. The humic components of organic matter, namely, humic acid and fulvic acid, were also separated out to study their effect, if any, on soil sorptivity. Steady state cumulative infiltration was highest in non-cultivated deltaic soil (NCD) (4.8-5.3 cm) followed by mudflat (MUD) soil (3.1-3.3 cm) and depressed low land (DL) soil (1.8-2.0 cm). The highest sorptivity ($3.4-3.5 \text{ mmmin}^{-1/2}$) was observed in NCD soil, followed by $2.2-2.5 \text{ mmmin}^{-1/2}$ in MUD soil and $0.90-1.0 \text{ mmmin}^{-1/2}$ in DL soils. 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 deltaic soils were higher than depressed low soils because of higher fulvic acid content in deltaic soil (0.14-0.15%) than depressed soils (0.09-0.1%). Saturated moisture was high in depressed low soil. Mud flat (MUD) soils showed intermediate sorptivity. Sorptivity decreased as the clay content, pH, EC, porosity and humic acid content of the soil increased (correlation coefficient, r values were -0.90, -0.86, -0.86, -0.87 and -0.90, respectively). Percentage fulvic acid was positively correlated with soil sorptivity (r value is+ 0.94). The correction of soil pH and EC, and modification of soil texture with adoption of appropriate amendments were suggested for improving sorptivity particularly of the depressed low land and MUD soils of the study area.

Key words: Infiltration, humic acid, fulvic acid, landforms

Introduction

Soil organic matter (SOM) contains almost all essential plant nutrients and plays a pivotal role in crop production. For sustainable utilization of soil resources, SOM should be maintained at a threshold level (Raychaudhuri, 1960). The status

of SOM of tropical countries like India is generally much below the threshold levels. The soil salinity and cropping behaviour under different landforms also have an important influence on soil organic matter (Goswami, 1998).

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

*Corresponding author,
Email: shi_cssri94@yahoo.com

causes erosion, flooding and degradation of water quality (Lal and Shukla, 2005). Infiltration is one of the major components of the hydrologic cycle (Hillel, 1980). It 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. Soil infiltration and sorptivity are also affected by different components of SOM like humic acid, fulvic acid and humin. Intensification of agriculture with adoption of multiple cropping systems and energy intensive cultivation practices, especially excessive tillage and imbalanced use of chemical fertilizers have influence on SOM. Hence 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. Study of the influence of salinity on organic matter in tidal wetlands showed that salinity was strongly negatively correlated with soil organic matter (OM) content (Morrissey *et al.*, 2014).

Many models have been developed to describe liquid infiltration in a porous material, including those by Parlange and co-workers (Smith and Parlange, 1978; Hill, 1972; Barry *et al.*, 1995; Parlange *et al.*, 2002; Lockington and Parlange, 2003). These models predict the time-rate of infiltration and the cumulative volume of infiltration based on parameters like the sorptivity S (Tindall and Kunkel, 1999), which quantifies the effect of capillarity on a liquid's movement in a material. Soil sorptivity is defined as the ability of a soil to absorb water during infiltration. Theoretically, Philip (1957) had 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 i.e., $I = St^{1/2}$ where S is a constant and is called sorptivity, I is cumulative infiltration. Sorptivity, $S = (\theta_0 - \theta_i)(\bar{D}/t)^{1/2}$, where $\bar{D}$ is weighted mean diffusivity, θ_i is initial soil water content, θ_0 is saturated wetness and t is time. Sorptivity is defined only in relation to a

fixed initial soil moisture state θ_i and an imposed boundary condition θ_0 . This is true for $t > 0$. Sorptivity can be measured based on different methods like estimating cumulative infiltration versus time, and independent measurement of hydraulic conductivity but the estimated sorptivity values measured by different methods should be in good agreement (Bisdom *et al.*, 1993). The presence of hydrophobic waxes on soil particles like humic acid / fulvic acid and other long chain organic compounds make the soil water repellent / wettability. Again, the fractions of humic components of organic matter may differ due to the presence of different plant covers like forest, cropland etc. Similarly, the humic / fulvic acid fractions of organic matter may be influenced by different landforms (Mandal and Jayaprakash, 2009; Doerr *et al.*, 1996; Franco *et al.*, 2000; Karnok *et al.*, 1993; Singh and Das, 1992). Water sorptivity on the surface of a large intact block of soil (0.9 m wide, 1.3 m long, 0.25 m deep) taken from a grassland site was measured and examined the effects of surface elevation and water repellency on water sorptivity at the millimeter scale. The soil block was partially dried to 0.22 mm³ mm⁻³, appeared to wet readily, and is not severely water repellent at any water content. Water sorptivity varied from 0.1 to 0.8 mm s^{-1/2} across the sampling grid with a coefficient of variation (CV) of 0.57 (Hallett *et al.*, 2004). The effect of water regimes on soil sorptivity and humic components of organic matter was studied. Steady state cumulative infiltration was the highest (60-100 mm) in non-irrigated upland soil and the lowest (8-10 mm) in waterlogged soil. The highest sorptivity of 4.0-4.5 mm min^{-1/2} was found in non irrigated upland soil and the lowest in seasonally waterlogged soil (1.0-1.5 mm min^{-1/2}) (Raut *et al.*, 2012). Information on the influence of different fractions of organic material such as humic acid, fulvic acid and humin on soil wettability / repellency in relation to different landforms is meagre. The study of the relationship between sorptivities and humic acid components of organic matter in Coastal West Bengal soils is also meagre. Therefore, present investigation was carried out to study the effect of three different landforms on soil sorptivities and on the

composition of soil organic matter and to study the effect of different fractions of organic matter towards water repellency / soil wettability particularly in a depressed low land soil.

Materials and methods

Soil samples were collected for two different seasons from three different depths (0-20, 20-40, 40-60 cm) from Gosaba villages (Lat. 20°30'-20°33' N; Long. 86°30'-86°32' E) of Gosaba Block of West Bengal (India) coming under three different landforms namely non-cultivated deltaic (NCD), depressed low (DL) land and mangrove / mudflat (MUD) (NCD: south east of the study area, DL: extreme south and MUD: middle, near Gosaba village; Fig. 1). It covers approximately four sq. km area. The seasons for collections were June- July, 2016 (before rice cultivation, 1st season) and Jan-Feb., 2018 (after rice cultivation, 2nd season). The area is mostly mono-cropped (rice cultivated). Soil samples were collected from

three different locations (three replications) and from three different depths under each landforms (Fig. 1). The horizontal infiltration and sorptivities were studied in plexiglass columns in the laboratory. The columns were prepared placing plexiglass segments (0.01 m height and 32 in number) one over another. These 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 and the distance from the water source to wetting front was visually observed with a scale fitted with the plexiglass column. 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 by using the following formula (Bruce and Klute, 1956) :



Fig. 1. Study area showing non cultivated deltaic (NCD), mudflat /mangrove (MUD) and depressed low land (DL)

$$D(\theta) = -1/2t \cdot dx/d\theta \big|_{x=d\theta} \quad \dots(1)$$

t is time; x is distance in eq. 1.

The equation 1 is solved between initial wetness (θ_i) and final wetness (θ). The weighted mean diffusivity was calculated according to Crank's (1956) formula:

$$\bar{D} = 1.66 / (\theta_0 - \theta_i)^{5/3} + D(\theta_0 - \theta_i)^{2/3} d(\theta) \quad \dots(2)$$

$\bar{D}$ is weighted mean diffusivity, θ_i is initial moisture content, θ_0 is saturated moisture content $D(\theta)$ is soil-water diffusivity in eq. 2.

Physicochemical characteristics like soil texture, pH, EC, organic C etc. were also studied. Cumulative infiltration was plotted as a function of time (Fig. 2 and 3). The physicochemical characteristics of the soils were determined using conventional methods. Particle size analysis was done using a Buoycous hydrometer. Organic carbon was estimated by modified Walkley and Black (1934) method, actual organic carbon (%) was multiplied by Van Bemmelen factor (1.724) to estimate % of organic matter. pH and electrical conductivity (EC) were measured in 1: 2 soil :

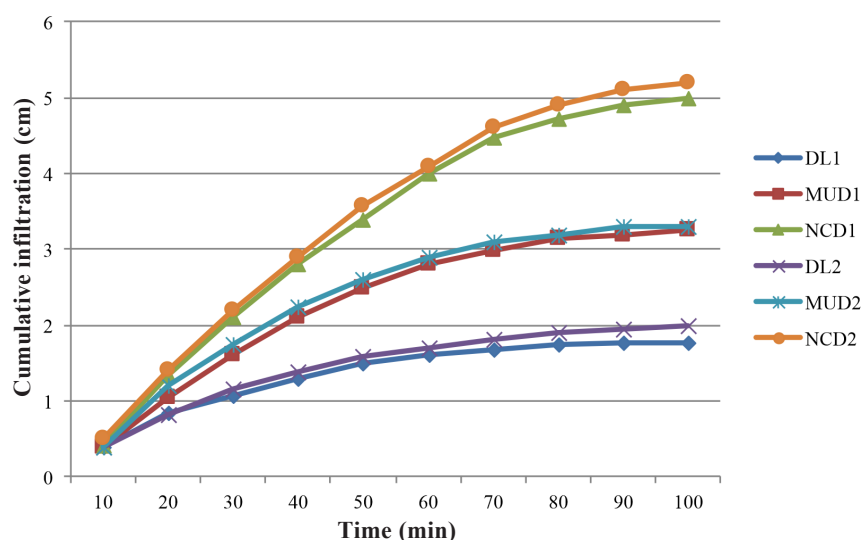


Fig. 2. Cumulative infiltration as a function of time (1: 1st season (June- July, 2016 (before rice cultivation)); 2: 2nd season (Jan-Feb., 2018 (after rice cultivation)); NCD: non cultivated deltaic, MUD: mudflat / mangrove, DL: depressed low land)

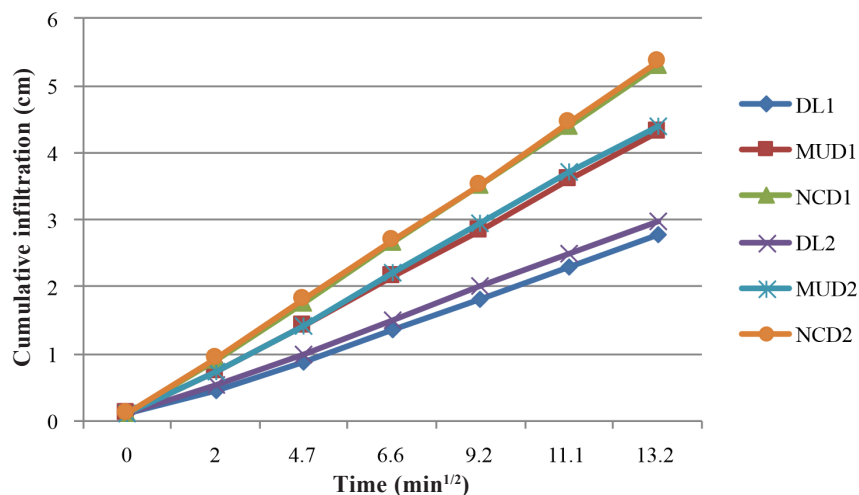


Fig. 3. Cumulative infiltration as a function of square root of time (1: 1st season (June- July, 2016 (before rice cultivation)); 2: 2nd season (Jan-Feb., 2018 (after rice cultivation)); NCD: non cultivated deltaic, MUD: mudflat / mangrove, DL: depressed low land)

water ratio. Saturated water content of the soils was determined by using Keen's box. The humic acid and fulvic acid fractions of organic matter were separated following the procedures of Kononova (1966). Relationship between sorptivity and other soil parameters were also determined. Correlation between clay and organic C as well as clay plus silt and organic carbon for the soils was studied.

Results and Discussion

Physicochemical Properties and Soil Sorptivities

The highest steady state cumulative infiltration was observed in non cultivated deltaic (NCD) soil (48-53 mm) followed by mudflat (MUD) soil (31-33 mm) and depressed low (DL) soil (18-20 mm). This result can be verified from the slope of the cumulative infiltration and time curves (Fig. 3). In 50 minutes time only 14-15 mm water infiltrated in DL soil. For the same period 32-36 mm water infiltrated in NCD soil. Infiltration in MUD soil was medium (23-25 mm). Clay content in non cultivated deltaic soil (NCD) varied from 24-63% and was sandy clay loam to clay loam. In the 20-40 cm and 40-60 cm soil layer for MUD and DL soils clay content did not differ much (40-54 %, sandy clay to clay). All

three soils (NCD, MUD and DL) were low to high in organic matter content (0.50-1.20%), the surface layer of NCD soil contained higher fraction (>1%) of organic matter (Tables 1 and 2). The highest porosity or saturation water content was found in DL soil (0.44-0.51 cm³cm⁻³) and the lowest was in MUD soil (0.36-0.45 cm³cm⁻³) in the surface layer (Table 3 & 4). The NCD and DL surface soils were slightly acidic to neutral (pH 5.0 to 7.4). The EC values of NCD soils were low for all depths (2.0 to 3.7dS / m; Tables 1 and 2). Water content of air dried soil before initiation of infiltration (θ_i), final water content (θ_0) and water gain during infiltration ($\theta_0 - \theta_i$) are presented in Tables 3 and 4. Average water content in soils after infiltration varied from 0.40-0.50 cm³cm⁻³ in NCD and 0.36-0.48 cm³cm⁻³ in MUD soils, whereas values were 0.43-0.52 cm³cm⁻³ in DL soils. Highest sorptivity (2.2-3.5 mmmin^{-1/2}) was observed in NCD soil, followed by 2.1-2.5 mmmin^{-1/2} in MUD soil and 1.0-1.5 mmmin^{-1/2} in DL soils. Sorptivity values differ significantly for three different landforms for different depths. These results can also be verified from the slope of the cumulative infiltration versus square root of time relationship curves (Fig. 3). The slope of NCD soils in the present study were higher than the MUD and DL soils. The seasonal variation of cumulative infiltration

Table 1. Physicochemical characteristics of Gosaba soil (1st season)

Name of soil	Particle size (%)			Texture	Org C	pH	EC (dS m ⁻¹)	θ _s (m ³ m ⁻³)
	S	Si	C					
0-20 cm								
NCD	16	55	29	Scl	1.19	5.0	3.7	0.59
MUD	26	22	52	C	1.19	6.9	9.3	0.54
DL	26	24	50	C	0.85	5.9	13.2	0.59
20-40 cm								
NCD	24	47	29	cl	1.13	5.7	3.6	0.56
MUD	26	20	54	C	0.71	6.9	6.9	0.55
DL	20	28	52	C	0.80	6.2	8.3	0.61
40-60cm								
NCD	25	45	30	cl	0.78	5.7	2.8	0.53
MUD	26	20	54	C	0.71	7.0	6.9	0.55
DL	28	20	52	C	0.80	6.0	8.0	0.60

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

Table 2. Physicochemical characteristics of Gosaba soil (2nd season)

Name of soil	Particle size (%)			Texture	Org C	pH	EC (dS m ⁻¹)	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	26	27	47	cl	0.62	7.4	4.2	0.67
20-40cm								
NCD	24	48	28	cl	1.10	6.2	2.0	0.66
MUD	40	20	40	SaC	0.64	7.7	5.8	0.63
DL	18	34	48	C	0.54	7.6	4.6	0.63
40-60cm								
NCD	13	24	63	cl	0.51	5.9	2.0	0.63
MUD	32	24	44	SaC	0.64	7.5	3.8	0.64
DL	24	16	50	C	0.50	7.4	4.9	0.68

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

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 (mm min ^{-1/2})
0-20 cm				
NCD	0.03	0.50	0.47	2.5
MUD	0.02	0.45	0.43	2.1
DL	0.04	0.51	0.47	1.5
20-40 cm				
NCD	0.04	0.49	0.45	2.4
MUD	0.03	0.46	0.43	2.2
DL	0.05	0.50	0.45	1.0
40-60 cm				
NCD	0.04	0.50	0.46	2.2
MUD	0.04	0.48	0.44	2.1
DL	0.05	0.52	0.47	1.0

NCD: non cultivated deltaic, MUD: mudflat/mangrove, DL: depressed low land; $F_{2,6} > F_{\text{tab}} (1\%)$; CD = 1.1; $T_1 = 7.1$, $T_2 = 6.4$, $T_3 = 3.5$

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 (mm min ^{-1/2})
0-20 cm				
NCD	0.02	0.40	0.38	3.5
MUD	0.02	0.36	0.34	2.5
DL	0.03	0.44	0.41	1.1
20-40cm				
NCD	0.04	0.41	0.37	3.3
MUD	0.03	0.36	0.33	2.3
DL	0.04	0.43	0.39	1.0
40-60cm				
NCD	0.04	0.41	0.37	3.1
MUD	0.03	0.41	0.38	2.1
DL	0.04	0.44	0.40	1.0

NCD: non cultivated deltaic, MUD: mudflat/mangrove, DL: depressed low land; $F_{2,6} > F_{\text{tab}} (1\%)$; CD = 1.0; $T_1 = 9.9$, $T_2 = 6.9$, $T_3 = 3.1$

may be associated with the cultivation practices i.e., root activity apart from the variations due to soil texture (Ghildyal and Tripathi, 1987). In the present study the seasonal variation of cumulative infiltration in different soils was low (Fig. 2 and 3). However, soil samples collected in Jan.-Feb., 2018 (2nd season) showed higher cumulative infiltration than soils collected in June-July, 2016

(1st season). The cumulative infiltration for NCD soil was higher than MUD and DL soils. During rice cultivation DL soils were puddled. High clay content facilitates puddling resulting in the decrease in non-capillary pore spaces which in turn decreases infiltration in the present study in the case of DL soils (Fig. 2 and 3). In our study the cumulative infiltration of NCD soils was about

2.5 times higher than that of DL soils. This result is in agreement with those reported by Singh and Bhargava (1993). Organic carbon content of coarse soils are usually lower than clayey soils (Zinn *et al.*, 2005) for all depths. In the present study, for all landforms, organic carbon percentages decreased with soil depths (Tables 1 and 2) and organic carbon content of NCD soils (0.51-1.20%) were more than that of MUD (0.64-1.19%) and DL (0.50-0.85%) soils. The relatively high porosity (0.43-0.52 m³m⁻³) value of different layers of DL soil as compared to other soils was associated with more clay content in DL soil (Tables 3 and 4). Similarly, the high porosity of MUD soils were also associated with high clay content for all the three layers. EC values for the NCD soils were low (2.0-3.7 dS/m), which decreased slightly with soil depth. High EC value in the surface layer might be associated with more accumulation of salt in the surface due to inundation. Sorptivity values differ significantly for soils of three different landforms for different depths (Tables 3 and 4). The vertical sorptivity studied in India was 2.2 cm min^{-1/2} in Eucalyptus stand and 3.2 cm min^{-1/2} under cropland (Mandal and Jayprakash, 2009). Sorptivity in the present study is mostly affected by crop root and soil texture for different soils. Sorptivity in the NCD fields was about 40-68% higher than DL fields. The saturated moisture content of all the soils differed slightly. The textural classes of MUD and DL soils were similar (sandy clay to clay) (Table 1 and 2). The higher sorptivity of NCD soils over DL soils (Table 4 and 5) at all depths might also have been attributed to the presence of differential components of humic substances. (Bhattacharya *et al.*, 2008).

Humic Substances

The humic acid (H.A.) and fulvic acid (F.A.) fractions of organic matter in the present study were separated by Kononova (1966) method and are given in Table 5. Fractionation of organic matters showed that the fraction of H.A. was the highest (0.31%) in DL soil and the fraction of F.A. was the lowest (0.10%) in the surface layer of the same soil. On the other hand, the F.A. fraction was the highest in NCD soil (0.13%).

MUD soils showed low values (0.09-0.10% FA). In the lower soil layers also H.A. % was higher in the DL soils (0.26 to 0.30%). The H.A. / F.A. ratio decreased with depth (0.69 to 0.55 for NCD and 3.1 to 2.88 for DL soils) (Table 5). The relatively lower ratio values indicated higher soil sorptivity. Presence of humic acid in soil generally decreases volumetric water content of soil. Decline in water repellency of soil is due to the presence of water soluble fulvic acid. The NCD soils in the present study had higher fraction of fulvic acid (0.11-0.13%) for which these were more capable of infiltration, whereas DL soils with greater fraction of insoluble humic acid (0.26-0.31%) were water repellent and exhibited less cumulative infiltration. MUD soils showed intermediate humic acid and fulvic acid contents (Dyke *et al.*, 2009; Singh and Das, 1992) (Table 5; Fig. 2 and 3).

The relationships between sorptivity and clay, pH, EC, porosity and humic acid were highly significant ($r = -0.90^*$, -0.86^{**} , -0.86^* , -0.87^* and -0.90^* , respectively), exponential and negative (Table 6). Percentage fulvic acid was positively correlated ($r=+0.94^*$) with sorptivity.

Table 5. Humic acid and fulvic acid content of organic matter and their ratio (pooled data for two seasons)

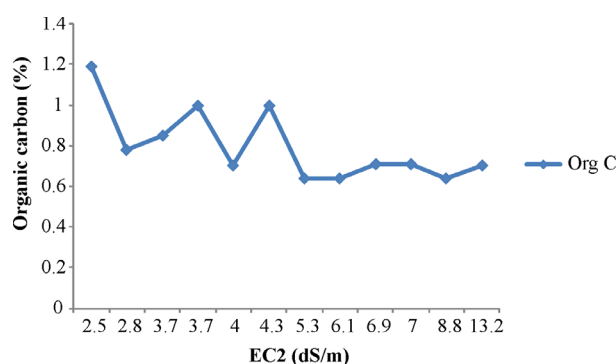
Name of soil	Total organic matter (%)	H.A (%)	F.A. (%)	H.A./ F.A. ratio
0-20 cm				
NCD	2.03	0.09	0.13	0.69
MUD	1.51	0.17	0.10	1.70
DL	1.33	0.31	0.10	3.10
20-40cm				
NCD	1.76	0.08	0.13	0.62
MUD	1.15	0.15	0.10	1.50
DL	1.20	0.30	0.10	3.00
40-60cm				
NCD	1.11	0.06	0.11	0.55
MUD	1.13	0.13	0.09	1.45
DL	1.05	0.26	0.09	2.88

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

Table 6. Relation between soil sorptivity (S) and other parameters (X) of soil (pooled data for two seasons)

Soil parameter	Correlation coefficient (r)	Regression equation
% Clay	-0.90*	$S = 6.2 e^{-0.03x}$
pH	-0.86**	$S = 6.4 e^{-0.17x}$
EC (dS/m)	-0.86*	$S = 3.9 e^{-0.07x}$
Porosity (%)	-0.87*	$S = 80.1 e^{-6.2x}$
H.A. (%)	-0.90*	$S = 4.1 e^{-2.31x}$
F.A. (%)	+0.94*	$S = 0.96 e^{8.9x}$

**Significant at 5% probability level, *significant at 1% probability level; S is sorptivity ($\text{mmmin}^{-1/2}$)

**Fig. 4.** Relation between salinity and organic carbon in soils of different landforms

With increase in soil salinity in general, there was a decrease in organic carbon content (Fig. 4). The high organic carbon values at salinity 3.7 dS/m and 4.3 dS/m may be attributed to the addition of organic matter in those plots.

Conclusions

Cumulative infiltration, sorptivity and various physico-chemical parameters of soils collected from three different landforms namely, non cultivated deltaic (NCD), Mud flat (MUD) and depressed low land (DL) were studied. Nature of organic matter was also studied and water management implications were depicted. The NCD soil was having higher cumulative infiltration (4.8-5.3 cm) than MUD soil (3.1-3.3 cm) and DL soil (1.8-2.0 cm). The NCD soils in the present study had higher fraction of fulvic acid (0.11-0.13%) for which these soils might

have declined water repellency and were more capable of infiltration, whereas DL soils contained higher fraction of insoluble humic acid (0.26-0.31%) and exhibited less cumulative infiltration. The humic acid-fulvic acid ratio in the present study also affected cumulative infiltration. The seasonal variation of cumulative infiltration might be associated with the cultivation practices i.e., root activity apart from the variations due to soil texture (Ghildyal and Tripathi, 1987). For this reason, cumulative infiltrations in the 2nd season might be slightly higher than those of 1st season. The influence of different seasons on soil sorptivity was low. In soils where cumulative infiltration is low (DL) (1.9-2.0 cm) to intermediate (MUD) (3.0-3.2 cm), adoption of suitable management practices such as deep ploughing, addition of sand and vertical drainage will be helpful for improving productivity of the soils. However, the correction of soil pH and EC, and modification of soil texture with adoption of appropriate amendments will help in improving sorptivity of all the three kinds of soils. Addition of organic matter (3-4 t/ha) in the NCD and DL soil is needed to improve organic carbon status and to lower salinity status of soil. In mangrove / mudflat it is necessary to study soil salinity more frequently to take any remedial measures.

Acknowledgement

Authors acknowledge Director, CSSRI for his help and support during doing the research.

References

- Barry, D.A., Parlange, J.Y., Haverkamp, R. and Ross, P.J. 1995. Infiltration under ponded conditions: An explicit predictive infiltration formula. *Soil Sci.* **160**: 8-17.
- Bhattacharya, R., Kundu, S., Pandey, S.C., Singh, K.P. and Gupta, H.S. 2008. Tillage and irrigation effects on crop yields and soil properties under the rice wheat system in the Indian Himalayas. *Agricultural Water Management* **95**: 9-18.
- Bisdorf, E.B.A., Dekker, L.W. and Schoultz, J.F. 1993. Water repellency of sieve fractions from sandy soils and relationships with organic material and soil structure. *Geoderma* **56**: 105-118.

- Bruce, R.R. and Klute, A. 1956. The measurement of soil moisture diffusivity. *Soil Science Society of America Proceedings* **20**: 458-62.
- Crank, J. 1956. In: *The mathematics of diffusion*. Oxford University Press, London and New York.
- Doerr, S.H., Shakesby, R.A. and Walsh, R.P.D. 1996. Soil hydrophobicity variations with depth and particle size fraction in burned and unburned *Eucalyptus globules* and *Pinus Pinaster* forest terrain in the Agueda basin, Portugal. *Catena* **27**: 25-47.
- Dyke, A.V., Johnson, P.G. and Grossl, P.R. 2009. Humic substances effect on moisture retention, nutrition, and colour of Intermountain West Putting Greens. *USGA Turfgrass and Environ. Research Online* **8**: 1-9.
- Franco, C.M.M., Clarke, P.J., Tate, M.E. and Oades, J.M. 2000. Hydrophobic properties and chemical characterizartion of natural water repellent materials in Australian sands. *Journal of Hydrology* **231**: 47-58.
- Ghildayal, B.P. and Tripathy, R.P. 1987. In: *Soil Physics*. Wiley Eastern Ltd., New Delhi.
- Goswami, N.N. 1998. *Soil organic matter and organic residue management for sustainable productivity*. In: Key note address. Indian Soc. Soil Science Res. Bul. 19.
- Hallett, P.D., Nunan, N., Douglas, J.T. and Young, I.M. 2004. Millimeter-scale spatial variability in soil water sorptivity: Scale, surface elevation, and subcritical repellency effects. *Soil Sci. Soc. Am. J.* **68**: 352-358.
- Hill, D.E. 1972. Wetting front instability in layered soils. *Soil Sci. Soc. Am. J.* **36**: 697-702.
- Hillel, D. 1980. In: *Applications of Soil Physics*. Academic Press, New York. 5-50.
- Karnok, K.A., Rowland, E.J. and Tan, K.H. 1993. High pH treatments and the alleviation of soil hydrophobicity on golf greens. *Agronomy Journal* **85**: 983-986.
- Kononova, M.M. 1966. In: *Soil Organic Matter*. Pergaman Press, Oxford, p. 45-46.
- Lal, Rattan, and Shukla, M.J. 2005. In: *Principles of Soil Physics*. Marcel Dekker, Inc. USA. 682p.
- Lockington, D. and Parlange, J.Y. 2003. Anomalous water absorption in porous materials. *J. Phys. D: Appl. Phys.* **36**: 760-767.
- Mandal, D. and Jayaprakash, J. 2009. Water repellency of soils in the lower Himalayan regions of India: impact of land use. *Current Science* **96**: 148-150.
- Morrissey, E.M., Gillespie, J.L., Morina, J.C. and Franklin, R.B. 2014. Salinity affects microbial activity and organic matter content in tidal wetlands. *Global Chang biol.* **20**: 1351-62.
- Parlange, J.Y., Barry, D.A. and Haverkamp, R. 2002. Explicit infiltration equations and the Lambert-W-function. *Adv. Water Resour.* **25**: 1119-1124.
- Philip, J.R. 1957. Study of water infiltration in the soil under different tillage practices. *Soil Science* **83**: 345.
- Raut, S., Sahoo, N. and Chakraborty, H. 2012. Effect of water regimes on sorptivity and organic matter humic components of soil. *International Agrophysics* **26**: 53-59.
- Raychaudhuri, S.P. 1960. *Effect of climate and cultivation on nitrogen and organic matter resources in Indian soils*. In: ICAR Res. Bul., New Delhi, India, 25 p.
- Singh, R. and Bhargava, G.P. 1993. Infiltration Characteristics of some Inceptisols. *Journal of the Indian Society of Soil Science* **41**: 218-223.
- Singh, R. and Das, D.K. 1992. Wettability of soil under different plant covers. *Journal of the Indian Society of Soil Science* **40**: 39 -43.
- Smith, R.E. and Parlange, J.Y. 1978. A parameter-efficient hydrological infiltration model. *Water Resour. Res.* **14**: 533-538.
- Tindall, J.A. and Kunkel, J.R. 1999. In: *Unsaturated zone hydrology for scientists and engineers*. Englewood Cliffs, Prentice-Hall.
- Walkley, A. and Black, C.A. 1934. An examination of Degtjareff methods for determining soil organic matter and a proposed modifications of the chromic acid titration method. *Soil Science* **37**: 29-38.
- Zinn, Y.L., Lal, Rattan and Resck, D.V.S. 2005. Texture and organic carbon relations described by a profile pedotransfer function for Brazilian Cerrado soils. *Geoderma* **127**: 168-173.