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Research Article

Effect of Water Regimes on Sorptivity, Nature of Organic Matter and Water Management Implications in different Soils of Coastal West Bengal

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ABSTRACT

Soils under three moisture regimes (irrigated cultivated, IC; non-irrigated uplands, NIU; and waterlogged, WL) were examined in terms of infiltration, sorptivity and fractions of organic matter content. Cumulative infiltration was the highest (8-10 mm) in NIU and lowest (1-2mm) in WL soils. The sorptivity was highest (3-3.5 mm $min^{-1/2}$) in NIU and lowest (1.5-2.0 mm $min^{-1/2}$) in WL soils. Organic C content and EC of all the soils were low (<2% and < 2 dS m^{-1}, respectively). Saturated moisture content was higher in waterlogged soil. The NIU soils had higher fulvic acid fraction (0.18-0.2%) and are lighter texture, due to which these soils exhibited higher infiltration. On the contrary, WL soils had larger fraction of insoluble humic acid (0.30-32%), which reduced the soil infiltration. Sorptivity decreased as the clay content, pH, EC, porosity and humic acid content of the soil increased (r values were -0.79, -0.75, -0.75, -0.80 and -0.85, respectively). Both the clay and clay-plus-silt contents were positively correlated with the organic C content (r^2 = 0.76 and 0.70, respectively). Correction of soil pH and EC, and modification of soil texture through amendments could help in improving sorptivity of the IC and WL soils.

Key words: Infiltration, Sorptivity, Humic acid, Fulvic acid, Soil water regime

Introduction

Sorptivity is the ability of soil to absorb water during infiltration. Theoretically, Philip (1957) has established that, in absence of gravity, amount of water absorbed during infiltration is proportional to the square root of time ($t^{1/2}$) when water is allowed to infiltrate into a horizontal soil column, the surface of which is maintained at a constant moisture content. The cumulative infiltration is expressed as I = St ½ where S is the sorptivity, which is defined as:

$$S = (\theta_o - \theta_i)\,(D/\pi)^{1/2},$$

where D is weighted mean diffusivity, θ_i and θ_o are initial and saturated wetness, and t is the time. Dependence of sorptivity and conductivity on soil density variations is nearly 5%. Good agreement between independent estimation of sorptivity and classical Phillip methods for horizontal infiltration under non-ponding condition was reported.

Hydrophilic or hydrophobic nature of soils is largely caused by differences in organic matter composition, and not by the amount of organic C (Mandal and Jayaprakash, 2009). Soils containing a large amount of hydrophobic materials such as plant litter, residue and microbial by-products may become water repellent or less wettable (Doerr *et al*., 1996; Bisdom *et al*., 1993). The

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accumulation of hydrophobic waxes on soil particles, humic and/or fulvic acid coatings and other long-chained organic compounds on or between soil particles are the major factors contributing to its hydrophobic nature (Franco *et al*., 2000; Karnok *et al*., 1993). Topography and rainfall are the factors to determine whether a soil will be waterlogged or not. Little information is available on the effect of organic material fractions like humic and fulvic acid, and humin on soil wettability/ repellency, resulting in water logging, especially in coastal areas of West Bengal. The study area has poor productivity of rice (2-3 t ha^{-1}). Moreover, in non-irrigated and waterlogged lands, water productivity is also poor. Keeping these in view, the study was carried out to know the effect of soil water regimes on the sorptivity and the composition of soil organic matter, and the effect of organic matter fractions towards water repellency/wettability of the soils.

Materials and Methods

Soil samples were collected twice (before and after rice) from two depths (0-15 and 15-30 cm) under three moisture regimes [non-irrigated upland, NIU: extreme north; irrigated cultivated, IC: extreme south; and seasonally water logged, WL: middle; Fig. 1] at Sonakhali village (22°31′-22°35′N, 88°53′-88°55′E) of Coastal West Bengal. The soils were classified as Aeric Endoaquepts and Typic Fluvaquents. The IC (summer rice) soils are irrigated 10-12 times with 2-4 h duration and each with 50-70 mm depth.

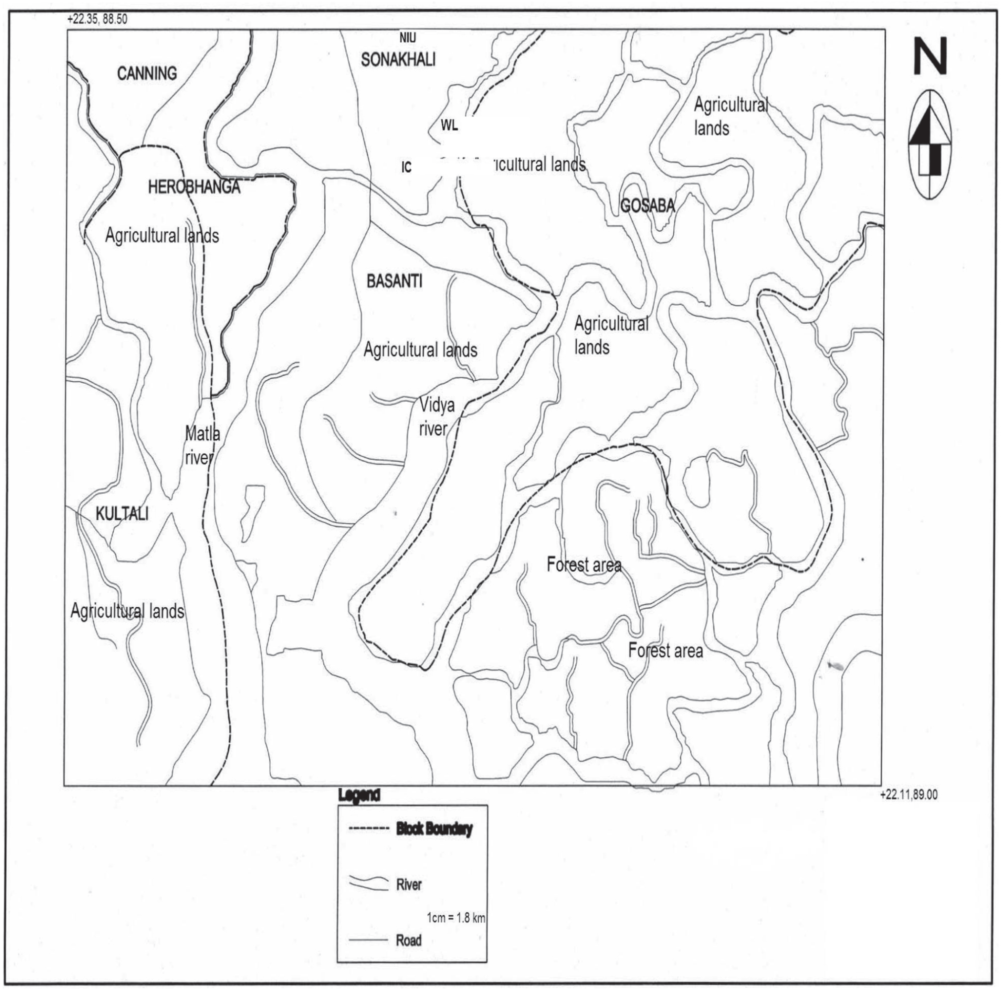

Fig. 1. The study area and sample locations (NIU: Non-irrigated uplands, WL: Water logged, IC: Irrigated cultivated)

The soils remain waterlogged for 3 months (September-November) and the depth of waterlogging is 1-1.5 m. The waterlogging was mostly because of finer soil texture and low topography. Soils were almost dry during sampling. Samples were collected in bulk using a spade from 0-15 and 15-30 cm depths and transferred to laboratory in polythene packets. Soils were air dried, ground and passed through a 2.0 mm sieve.

The horizontal infiltration and sorptivity were studied in plexiglass columns in the laboratory. The columns were prepared with plexiglass segments (0.01 m height and 32 in number) one over another. These were filled uniformly with bulk density of 1.3 Mg m^{-3}. Columns were placed horizontally on a wooden stand and water was introduced to the inlet end from mariotte tube at a constant suction of 0.2 kPa. Water entering the column was measured volumetrically and the distance from the water source to the wetting front was visually observed. After the infiltration, columns were sectioned into 1 cm segments and water content was determined gravimetrically. Soil water diffusivity, D(θ) was calculated by using the following formula:

$$D(\theta) = -1 /2t.\ dx/ d\theta \int x d\theta$$

where, t is time; x is distance; the definite integral is solved between initial wetness (θ_i) and final wetness (θ_o).

The weighted mean diffusivity (D) was calculated according to Crank's (1956) formula:

$$D = 1.66/ (\theta_o - \theta_i)^{5/3} \int D(\theta) (\theta_o - \theta_i)^{2/3} d\theta$$

Particle size analysis was done using a Buoycous hydrometer. Organic C was determined by Walkley and Black method, pH and electrical conductivity (E:C) were measured in 1:2 soil:water ratio. Saturated water content of the soils was determined by using Keen's box (Piper, 1950). The humic acid and fulvic acid fractions were separated by following the procedures of Kononova (1966). Relationship between sorptivity and other soil parameters and correlations between clay and EC, clay and organic C and clay+silt and organic C were also worked out.

Results and Discussion

Physico-chemical properties and soil sorptivity

The cumulative infiltration was highest in NIU soil (6-10 mm) followed by IC (6-8 mm) and WL (1-2 mm) soils. This is evidenced by the variation in slopes of the cumulative infiltration and time curves (Fig. 2). Only 1-2 mm water infiltrated in WL soil in 50 min, whereas 4-7 mm water infiltrated in NIU soil during similar time period. The IC soil showed medium infiltration (4-5 mm). The IC and WL soils were clayey with 44-64% clay contents in the surface layer (Table 1). Clay content in NIU soil was 40% (clay loam in texture). However, in 15-30 cm layer, clay content did not differ much between IC and WL soils (36-64 %, clayey). All the soils were low in organic matter content (<2%). The saturation water content was highest in WL soil (0.60-0.61 cm^3cm^{-3}) and lowest in NIU soil (0.51-0.52 cm^3cm^{-3}). The NIU and WL surface soils were slightly acidic to neutral (pH 4.8-6.0), although the EC was low for all the soils at all depths (0.0.1-1.6 dS m^{-1}; Table 1). Water content of air-dry soil before infiltration (q_i), final (q_0) and water gain during infiltration ($q_{0-}q_i$) are presented in Table 2 and 3. Average water content in soils after infiltration varied from 0.50-0.53 in IC and 0.50-0.51 cm^3cm^{-3} in WL soils, whereas values were 0.35-0.36 cm^3cm^{-3} in NIU soils. Highest sorptivity (3.3-3.5 mm $min^{-1/2}$) was observed in NIU soil, followed by 2.3-2.5 mm $min^{-1/2}$ in IC and 1.4-1.5 mm $min^{-1/2}$ in WL soils.

Sorptivity values differed significantly between moisture regimes and between depths.

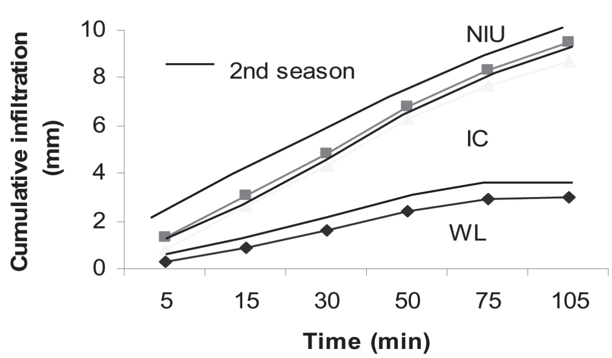

Fig. 2. Cumulative infiltration as a function of time for soils of three moisture regimes

Table 1. Physico-chemical characteristics of Sonakhali soil

Soil	Particle size (%)			Texture	Organic C (%)		pH		EC (dS m^{-1})		θ_s (cm^3cm^{-3})	
	Sand	Silt	Clay		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
0-15 cm												
NIU	36	24	40	cl	1.0	1.0	4.8	5.0	0.1	0.08	0.52	0.50
IC	40	16	44	c	1.1	1.2	5.8	5.8	1.3	1.2	0.59	0.57
WL	20	16	64	c	1.5	1.4	5.6	5.8	1.4	1.3	0.61	0.60
15-30 cm												
NIU	36	26	38	cl	0.9	0.9	5.5	4.8	0.7	0.07	0.51	0.48
IC	34	10	36	c	1.00	1.1	5.9	5.5	1.4	1.1	0.56	0.52
WL	20	16	64	c	1.4	1.3	6.0	5.7	1.6	1.2	0.60	0.55

NIU: non-irrigated upland, IC: irrigated cultivated, WL: waterlogged

Table 2. Water content of soil samples, gain in water content and sorptivity (1st season)

Soil	θ_i (cm^3cm^{-3})	θ_0 (cm^3cm^{-3})	θ_0-θ_i (cm^3cm^{-3})	Sorptivity (mm $min^{-1/2}$)
(0-15cm)				
NIU	0.01	0.35	0.34	3.5
IC	0.04	0.50	0.46	2.5
WL	0.05	0.51	0.46	1.5
(15-30cm)				
NIU	0.01	0.36	0.35	3.3
IC	0.03	0.53	0.50	2.3
WL	0.04	0.50	0.46	1.4

$F_{2,6} > F_{tab(1\%)}$; C.D. =2.7; T_1 = 11.9, T_2 = 7.0, T_3 = 4.0

Table 3. Water content of soil samples, gain in water content and sorptivity (2nd season)

Soil	θ_i (cm^3cm^{-3})	θ_0 (cm^3cm^{-3})	θ_0-θ_i (cm^3cm^{-3})	Sorptivity (mm $min^{-1/2}$)
(0-15cm)				
NIU	0.02	0.34	0.32	3.5
IC	0.04	0.50	0.46	2.5
WL	0.05	0.52	0.47	1.6
(15-30cm)				
NIU	0.01	0.34	0.33	3.5
IC	0.03	0.54	0.51	2.4
WL	0.07	0.53	0.46	1.5

$F_{2,6} > F_{tab(1\%)}$; C.D. =2.8; T_1 = 12.4, T_2 = 6.2, T_3 = 3.5

The slope of infiltration-time curve was higher in NIU than the IC and WL soils (Fig. 3). The seasonal variation of infiltration could be due to 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 was low (Fig. 2), although highest cumulative infiltration in soils was observed in the 2nd compared to the 1st season. During rice, soils are puddled. High clay content facilitates puddling, resulting in decrease in non-capillary pores. This decreases infiltration

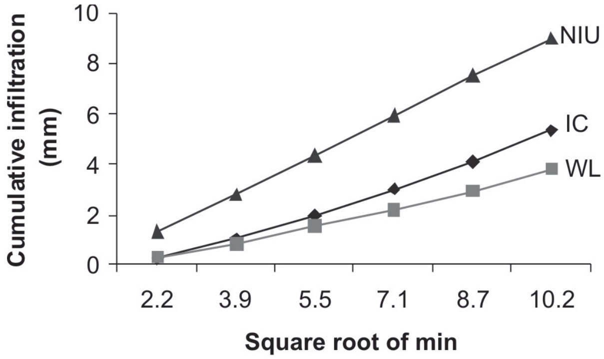

Fig. 3. Cumulative infiltration as a function of square root of time

in IC and WL soils (Fig. 2). In our study, the cumulative infiltration of NIU soils was 5 times higher than that of WL soils.

Organic C content of coarse soils are usually lower than clayey soils (Zinn *et al*., 2005). We have found C decreases with soil depth for all water regimes (Table 1). Organic C of NIU soils (0.9-1.0%) were less than that of IC (1.0-1.2%) and WL (1.3-1.5%) soils. The relatively high porosity of 15-30 cm layer of NIU soil as compared to the surface soil was associated with more clay content (Table 1). Similarly, high porosity of WL and IC soils were associated with high clay. The EC values for all three soils were low, which increased marginally with depth. This might be associated with more compaction with increased soil depth.

Sorptivity differed significantly for moisture regimes for different depths (Table 2 and 3). It is affected by tillage intensity and applied irrigation water. Sorptivity with frequent irrigation (IC fields) was 14-53% higher than soils with less frequency of (WL fields). Irrigation increases total porosity and pore continuity. For this reason, sorptivity of IC soils have been higher than that of the WL, although the textural classes of both fields were similar.

Humic substances

Fractionation of organic matter showed that humic acid (HA) was highest (0.32%) and the fulvic acid (FA) the lowest in WL soil (Table 4). On the other hand, the FA was highest in NIU soil (0.2%). The IC soils showed intermediate values (0.10%). In the lower layers, HA was higher in WL soils (0.30%). The HA/FA ratio decreased with depth (0.5 to 0.44 for NIU and 4.3 to 4.0 for WL soils).

Relationships between sorptivity and clay, pH, EC, porosity and humic acid were significant (at 1% probability level) (r = -0.79, -0.75, -0.75, -0.80 and -0.85, respectively), exponential and negative (Table 5). The FA was positively correlated (r=0.90, significant at 1% level) with sorptivity. The clay and clay plus silt were significantly (+ve) correlated with the percentage of organic C (r^2 = 0.75 and 0.72, respectively). Humus is the major soil organic matter component making up 75-80% of the total (Kononova, 1966). In alluvial soil it is 1.5-6% (Stevenson, 1965). The HA and FA ratio in the present study was 0.44-0.5 in the surface layers and decreased with

Table 4. Humic acid and fulvic acid content of Sonakhali soil (pooled data for two seasons)

Soil	Total organic matter (%)	H.A. (%)	F.A. (%)	H.A./ F.A. ratio
		(0-15 cm)		
NIU	0.68	0.1	0.2	0.5
IC	1.93	0.25	0.10	2.50
WL	1.68	0.32	0.08	4.0
		(15-30 cm)		
NIU	0.61	0.08	0.18	0.44
IC	1.24	0.25	0.10	2.5
WL	1.26	0.30	0.07	4.30

NIU: non irrigated upland, IC: irrigated cultivated, WL: waterlogged

Table 5. Relation between sorptivity (S) and other parameters (x) of soil

Soil parameter (x)	Correlation coefficient (r)	Regression equation
% clay	-0.79**	$S = 5.9\ e^{-0.02 \cdot x}$
pH	-0.75*	$S = 358\ e^{-0.87 \cdot x}$
EC (dS m^{-1})	-0.95**	$S = 18.5\ e^{-28.5 \cdot x}$
Porosity ($cm^3\ cm^{-3}$) (saturated water content)	-0.80**	$S = 30\ e^{-4.5 \cdot x}$
Humic acid (%)	-0.85**	$S = 5\ e^{-1.7 \cdot x}$
Fulvic acid (%)	0.90**	$S = 0.45\ e^{12.3 \cdot x}$

*significant at 5% probability level, **significant at 1% probability level, S is sorptivity (mm $min^{-1/2}$).

soil depth (Weil, 1993; Kononova *et al*., 1961). Presence of HA in soil generally decreases soil water content, while reduction in water repellency is due to the presence of water-soluble FA. The NIU had higher FA fraction (0.1-0.2%), which improves the infiltration, where greater fraction of insoluble HA (0.30-0.32%) imparted lower infiltration in WL soil (Dyke *et al*., 2009; Singh and Das, 1992; Raut and Chakraborty, 2008) (Table 4). Regression equations in Table 5 showed that sorptivity decreased as the clay content, pH, EC, porosity and HA content of the soil increased (r values are -0.79, -0.75, -0.75, -0.80 & -0.85, respectively). These were in agreement with the findings of Singh and Kundu (2001) for Orissa soils.

The clay content was the best predictor of organic C. The clay content and clay plus silt were significantly (+ve) correlated with organic C (r^2 = 0.75 and 0.72, respectively). This may be attributed to the decrease in C mineralization with increase in finer sized particles. In other words, pores of smaller sizes protect organic substrates against microbial decomposition in soils (Mtambanengwe *et al*., 2008). Soil EC are positively correlated with clay (r=0.46-0.50).

Conclusions

In soils where cumulative infiltration and sorptivity are low (waterlogged soil) to intermediate (irrigated cultivated), adoption of suitable management practices such as deep ploughing, addition of sand and vertical drainage for *in situ* water conservation are necessary to improve water use efficiency. Seasons have minimal influence on soil sorptivity. Addition of organic matter in the non-irrigated upland soil is needed to improve the water holding capacity.

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