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# Effect of water regimes on sorptivity and organic matter humic components of soil

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Abstract. The aim of the study was to find the effect of water regimes on soil sorptivity and humic components of organic matter. Physicochemical parameters were also determined. 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$^{-1/2}$). Organic carbon content of all soils was low (<1%), EC values were also low (< 4 dS m$^{-1}$). Saturated moisture was high in waterlogged soil. The non-irrigated upland soils had a higher fraction of fulvic acid (0.15-0.2%), due to which they were more capable of infiltration, whereas waterlogged soils had a greater fraction of insoluble humic acid (0.29-0.35%) and exhibited less cumulative infiltration. Sorptivity decreased as the clay content, pH, EC, porosity and humic acid content of the soil increased.

Keywords: infiltration, soil sorptivity, humic acid, fulvic acid

## INTRODUCTION

The ability of a soil to absorb water during infiltration is called sorptivity. Theoretically, it has established that, in the 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 *ie* $I = St^{1/2}$ where *S* is a constant and is called sorptivity, *I* is cumulative infiltration. Sorptivity, $S = (\theta o - \theta i)(D / t)^{1/2}$, where $D$ is weighted mean diffusivity, $\theta_i$ is initial soil water content, $\theta_o$ is saturated wetness and *t* is time. Sorptivity is defined only in relation to a fixed initial state $\theta_i$ and an imposed boundary condition $\theta_o$. This is true for $t > 0$ (Kirkham, 2005; Rehman, 2010; Youngs, 1968). Typical values of the steady infiltration rate for sandy and silty soils, loams and clayey soils are 10-20, 5-10, and 1-5 mm h$^{-1}$, respectively (Harden and Scruggs, 2003; Yang *et al*., 2004). The differences in wettability of soils are caused by differences in organic matter composition rather than by the amount of organic carbon (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 (Bisdom *et al*., 1993; Doerr *et al*., 1996). These materials are generally thought to be present as a coating on soil particles or aggregates (Bisdom *et al*., 1993). The accumulation of hydrophobic waxes on soil particles, such as humic acid, as soil coatings and other long-chained organic compounds on or between soil particles are all accepted as factors contributing to this negative impact phenomenon (Franco *et al*., 2000; Karnok *et al*., 1993). Wettability of soil is also greatly influenced by nature of decomposed organic materials (Singh and Das, 1992). For these reasons, soils under sal (*Shorea robusta*) forest, chrysopogon grass (*Chrysopogon aciculatus*) and cropland have less water drop penetration time and therefore are classified as wettable. However, soils under eucalyptus plantation and panicum stand, containing a higher fraction of humic acid, show considerable hydrophobicity.

Topography and rainfall are the main factors which determine whether a soil would be waterlogged or not. But information on the influence of different fractions of organic material such as humic acid, fulvic acid and humin content on soil wettability/repellence and sorptivity, resulting in waterlogging particularly for Orissa (India) soils, is meagre.

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The present investigation was carried out to study the effect of the different fractions of soil organic matter on water repellence/soil wettability and sorptivity and waterlogging in relation to different water regimes.

## MATERIALS AND METHODS

Soil samples were collected from three different depths (0-15, 15-30, 30-45 cm), from Raghunathpur village (20° 30'-20°33' N; 86°30'-86°-32' E), Jagatsinghpur district of Orissa, India, in three different seasons coming under three different moisture regimes, namely, irrigated cultivated, seasonally waterlogged and non irrigated upland. The soils were classified as Typic Haplaquepts (Fig. 1). The study area was approximately 4 km$^2$. The seasons for soil collections were June - July, 2007 (before rice cultivation) and January - February, 2008 (after rice cultivation), and November - December, 2008 (after rice cultivation). The area is mostly mono-cropped (rice cultivation). Soil samples were collected from three different points (three replications) of each moisture regime, for a total of 81 samples, and processed. The horizontal infiltration and sorptivity were studied in a plexiglass column in the laboratory. The column was prepared placing plexiglass segments (0.01 m height and 32 in number) one over another. This was filled separately, as uniformly as possible, with different soil samples at bulk density of 1.3 Mg m$^{-3}$. The column was placed horizontally on a wooden stand and water was introduced to the inlet end from marriotte tube at a constant pressure 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 completion of the infiltration, the column was sectioned into 1 cm segments and water content was determined gravimetrically. From these, soil water diffusivity, $D(\theta)$, was calculated by using the following formula:

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

where: $x$ is distance, the definite integral is solved between initial wetness ($\theta_i$) and final wetness ($\theta$).

The weighted mean diffusivity was calculated according to Crank formula (Bai *et al.*, 2007):

$$D = 1.66/(\theta o - \theta i)^{5/3} D(\theta)(\theta o - \theta_i)^{2/3} d\theta, \qquad (2)$$

where: $D$ is weighted mean diffusivity.

Physicochemical characteristics of soils were determined by using standard procedures (Black, 1965; Jackson, 1973). Saturated water content of the soils was measured according to Rashid (2011). Cumulative infiltration was plotted as a function of time (Fig. 2). The humic acid and fulvic acid fractions of organic matter were separated according to Kononova (Swift, 2011). The relationships between sorptivity and other soil parameters, correlation between clay and organic carbon as well as clay + silt and organic carbon were also determined.

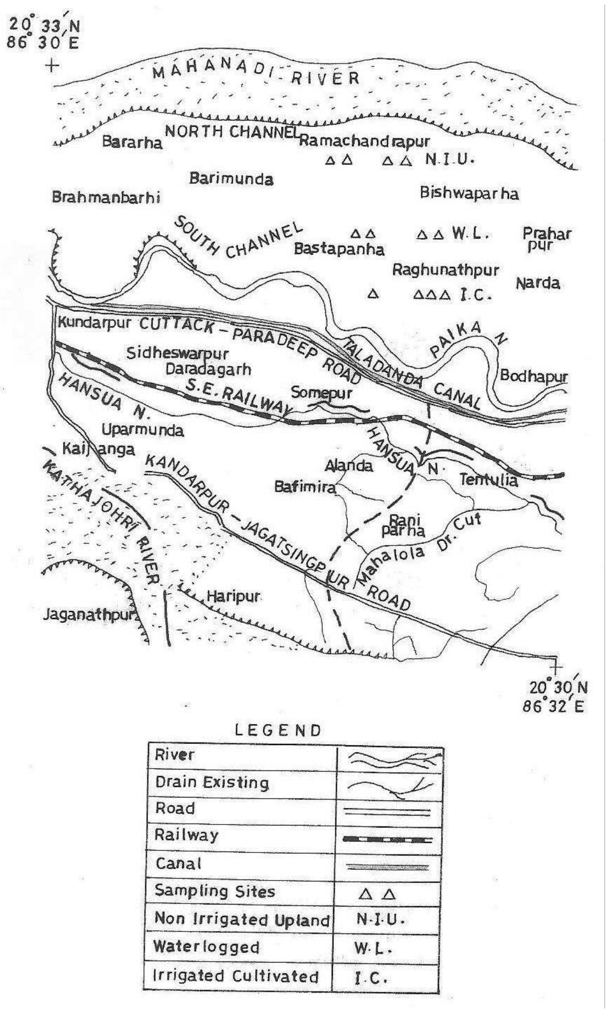

**Fig. 1.** The study area and sample locations.

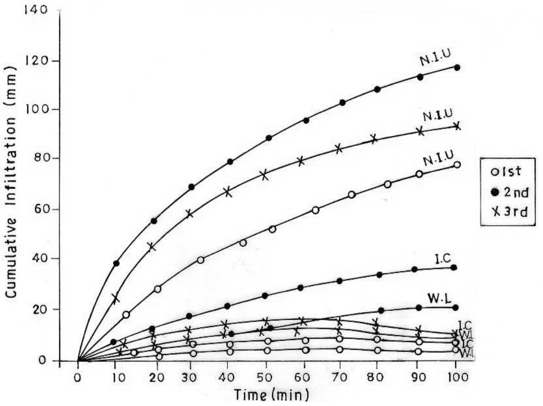

**Fig. 2.** Cumulative infiltration as a function of time for soils of three moisture regimes (NIU – non-irrigated upland, IC – irrigated cultivated, WL – waterlogged, 1st-2nd-3rd refer to seasons).

## RESULTS AND DISCUSSION

The highest steady state cumulative infiltration was observed in non-irrigated upland soil (55- 100 mm), followed by irrigated cultivated soil (10-20 mm) and seasonally waterlogged soil (6-18 mm) (Fig. 2). This result can be verified from the slope of the cumulative infiltration and time curves. In 50 min time only 5-13 mm water infiltrated in the waterlogged soil. Whereas, for the same period, 40-90 mm water infiltrated in the non-irrigated upland soil. Infiltration in the irrigated cultivated soil was medium (12-23 mm). Irrigated cultivated and waterlogged soils were clay, with a clay content of 69-83% in the surface layer (Table 1). Clay content in the non-irrigated upland soil varied from 21 to 35%, and the soil was sandy clay loam. Clay content did not differ much in the 15-30 and 30-45 cm soil layer for irrigated

**T a b l e 1**. Physicochemical characteristics of soils (1st, 2nd, and 3rd seasons)

| Soil | Depth (cm) | Particle size distribution (%) | | | $C_{org.}$ (%) | pH | EC (dS $m^{-1}$) | $\theta_s$ (vol.) |
|---|---|---|---|---|---|---|---|---|
| | | Sand | Silt | Clay | | | | |
| | | | | 1st season | | | | |
| NIU* | 0-15 | 69 | 10 | 21 | 0.31 | 5.2 | 0.05 | 0.46 |
| IC | | 13 | 18 | 69 | 1.10 | 5.4 | 0.07 | 0.64 |
| WL | | 9 | 8 | 83 | 1.00 | 5.6 | 0.08 | 0.69 |
| NIU | 15-30 | 51 | 12 | 37 | 0.33 | 5.6 | 0.06 | 0.49 |
| IC | | 1 | 22 | 77 | 1.00 | 5.9 | 0.08 | 0.64 |
| WL | | 1 | 20 | 79 | 0.96 | 6.0 | 0.09 | 0.69 |
| NIU | 30-45 | 71 | 8 | 21 | 0.36 | 5.7 | 0.05 | 0.47 |
| IC | | 27 | 4 | 69 | 0.98 | 6.0 | 0.08 | 0.57 |
| WL | | 21 | 6 | 73 | 0.95 | 6.5 | 0.09 | 0.63 |
| | | | | 2nd season | | | | |
| NIU | 0-15 | 63 | 2 | 32 | 0.68 | 5.0 | 0.05 | 0.37 |
| IC | | 27 | 2 | 71 | 1.33 | 5.8 | 0.07 | 0.57 |
| WL | | 21 | 4 | 75 | 0.95 | 6.0 | 0.08 | 0.60 |
| NIU | 15-30 | 71 | 8 | 21 | 0.54 | 6.5 | 0.04 | 0.38 |
| IC | | 27 | 4 | 69 | 0.95 | 6.6 | 0.07 | 0.59 |
| WL | | 29 | 2 | 69 | 0.96 | 6.7 | 0.07 | 0.61 |
| NIU | 30-45 | 79 | 2 | 9 | 0.40 | 5.9 | 0.05 | 0.47 |
| IC | | 27 | 4 | 69 | 0.90 | 6.0 | 0.08 | 0.57 |
| WL | | 21 | 6 | 73 | 0.90 | 6.7 | 0.11 | 0.59 |
| | | | | 3rd season | | | | |
| NIU | 0-15 | 65 | 15 | 20 | 0.40 | 5.0 | 0.07 | 0.40 |
| IC | | 28 | 2 | 70 | 1.00 | 5.8 | 0.09 | 0.51 |
| WL | | 10 | 15 | 75 | 0.95 | 6.2 | 0.11 | 0.55 |
| NIU | 15-30 | 55 | 12 | 23 | 0.30 | 6.2 | 0.06 | 0.39 |
| IC | | 26 | 4 | 70 | 0.95 | 5.4 | 0.10 | 0.50 |
| WL | | 5 | 19 | 76 | 0.98 | 6.5 | 0.12 | 0.52 |
| NIU | 30-45 | 52 | 14 | 34 | 0.29 | 6.0 | 0.05 | 0.42 |
| IC | | 27 | 5 | 68 | 0.90 | 6.2 | 0.12 | 0.53 |
| WL | | 6 | 20 | 74 | 0.95 | 6.6 | 0.12 | 0.54 |

*NIU– non-irrigated upland, IC – irrigated cultivated, WL – waterlogged.

**T a b l e 2.** Water content and sorptivity of soil samples (1st, 2nd, and 3rd seasons)

| Soil | Depth (cm) | $\theta_i$ | $\theta_0$ | $\theta_0$-$\theta_i$ | Sorptivity (mm min$^{-1/2}$) |
|---|---|---|---|---|---|
| | | | (vol.) | | |
| | | | 1st season | | |
| NIU | 0-15 | 0.01 | 0.29 | 0.28 | 4.0 |
| IC | | 0.04 | 0.47 | 0.43 | 2.5 |
| WL | | 0.05 | 0.47 | 0.42 | 1.6 |
| NIU | 15-30 | 0.01 | 0.31 | 0.30 | 4.0 |
| IC | | 0.03 | 0.53 | 0.50 | 2.3 |
| WL | | 0.04 | 0.49 | 0.45 | 1.3 |
| NIU | 30-45 | 0.01 | 0.35 | 0.34 | 3.9 |
| IC | | 0.04 | 0.60 | 0.56 | 2.2 |
| WL | | 0.04 | 0.60 | 0.56 | 1.2 |
| | | | 2nd season | | |
| NIU | 0-15 | 0.01 | 0.29 | 0.28 | 4.5 |
| IC | | 0.04 | 0.45 | 0.41 | 2.2 |
| WL | | 0.05 | 0.49 | 0.43 | 1.5 |
| NIU | 15-30 | 0.02 | 0.28 | 0.26 | 4.0 |
| IC | | 0.03 | 0.53 | 0.50 | 2.0 |
| WL | | 0.07 | 0.57 | 0.50 | 1.0 |
| NIU | 30-45 | 0.01 | 0.32 | 0.31 | 3.9 |
| IC | | 0.06 | 0.55 | 0.49 | 2.0 |
| WL | | 0.07 | 0.60 | 0.53 | 1.0 |
| | | | 3rd season | | |
| NIU | 0-15 | 0.02 | 0.30 | 0.28 | 4.4 |
| IC | | 0.03 | 0.41 | 0.38 | 2.3 |
| WL | | 0.06 | 0.50 | 0.44 | 1.6 |
| NIU | 15-30 | 0.02 | 0.29 | 0.27 | 4.2 |
| IC | | 0.05 | 0.45 | 0.40 | 2.0 |
| WL | | 0.07 | 0.55 | 0.48 | 1.2 |
| NIU | 30-45 | 0.01 | 0.32 | 0.31 | 4.0 |
| IC | | 0.07 | 0.42 | 0.35 | 1.7 |
| WL | | 0.07 | 0.58 | 0.51 | 1.1 |

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

cultivated and waterlogged soils (60-75%, clayey). All three soils were low in organic matter content (<1%), except for the surface layer of the irrigated cultivated soil which contained 1-1.33% organic matter. The highest porosity or saturation water content was found in the waterlogged soil (0.52-0.69 cm$^3$cm$^{-3}$) and the lowest was in the non-irrigated upland soil (0.37-0.47 cm$^3$cm$^{-3}$). The non-irrigated upland and waterlogged surface soils were slightly acidic to neutral (pH 5.6 to 6.8). The EC values of all the soils were low for all depths (0.04 to 0.12 dS m$^{-1}$, Table 1).

Water content of air dried soil before initiation of infiltration ($\theta_i$), final water content ($\theta_0$) and water gain during infiltration ($\theta_{0-i}$) are presented in Table 2. Average water content in soils after infiltration varied within the range of 0.41-0.60 cm$^3$cm$^{-3}$ in the irrigated cultivated soil and 0.47-0.60 cm$^3$cm$^{-3}$ in the waterlogged soil, whereas the values were 0.28-0.35 cm$^3$cm$^{-3}$ in the non-irrigated upland soil. The gains were higher in the irrigated cultivated and waterlogged soils. The highest sorptivity (3.9-4.5 mm min$^{-1/2}$) was observed in the non-irrigated upland soil, followed by 1.7-2.5 mm min$^{-1/2}$ in the irrigated cultivated soil and 1.0-1.6 mm min$^{-1/2}$ in the waterlogged soil. Sorptivity values differ significantly ($F_{tab\ (2,6)} > F_{cal}$) for the three different moisture regimes for different depths. These results can also be verified from the slope of the cumulative infiltration vs. $t^{1/2}$ relationship curves (Fig. 3). The slope of the non-irrigated upland soil in the present study was higher than those of the irrigated cultivated and waterlogged soils. The seasonal variation of cumulative infiltration may be attributed to the cultivation practices *ie* root activity, apart from the variations due to soil texture (Zheng *et al*., 2001). In the present study the seasonal variation of cumulative infiltration in the different soils was low (Figs 2, 3). This may be because of low variation of soil pH, EC, and organic carbon content of the soils in different seasons (Table 1), in addition to low textural variation. However, soil samples collected from the

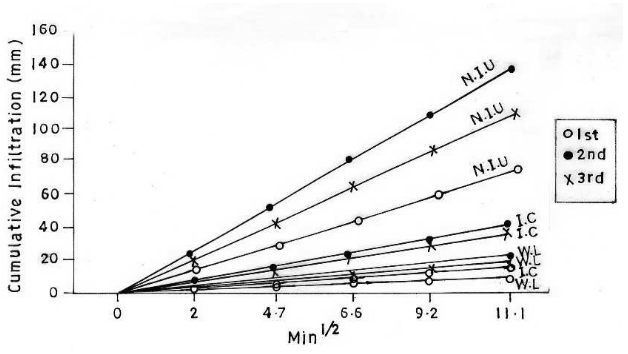

**Fig. 3.** Cumulative infiltration as a function of square root of time for soils of three moisture regimes. Explanations as in Fig. 2.

2nd season showed the highest cumulative infiltration compared to those collected in the 1st and 3rd seasons. During rice cultivation all these soils were puddled. High clay content facilitates puddling, resulting in a decrease in non-capillary pore spaces, which in turn decreases infiltration. The irrigated cultivated and waterlogged soils in the present study contained more clays, resulting in low infiltration (Fig. 2). In our study the cumulative infiltration of the non-irrigated upland soil was about 5 times higher than that of the waterlogged soils. This result is agreed to the results of Singh and Bhargava (1993) for soils of India.

Organic carbon content of coarse soils is usually lower than that of clayey soils (Zinn *et al*., 2005) for all depths. In the present study organic carbon percentages decreased with soil depths for all water regimes and organic carbon content of the non-irrigated upland soil (0.29-0.68%) was less than that of the irrigated cultivated (0.9-1.1%) and waterlogged (0.95-1.0%) soils (Table 1). The relatively high porosity value of the 15-30 cm layer of non-irrigated upland soil, as compared to the surface soil horizon, was associated with greater clay content (Table 1). Similarly, the high porosity of the waterlogged and irrigated cultivated soils was associated with high % of clay for all the three layers. This may be due to the fact that with an increase in the content of smaller-sized particles in the soil layers there is a decrease in bulk density of the soil. EC values for all three soils were low, and increased slightly with soil depth. This might be attributed to higher compaction at greater soil depth. The sorptivity values studied in the soils of Gujarat (India) were 6.9, 3.3 and 1.9 mm $\text{min}^{-1/2}$ for sandy loam soil, clay loam and clay soils, respectively (Singh and Bhargava, 1993). The vertical sorptivity studied in India was 2.2 cm $\text{min}^{-1/2}$ in eucalyptus stand and 3.2 cm $\text{min}^{-1/2}$ under crop-land (Mandal and Jayprakash, 2009). Sorptivity values in the present study differ significantly ($F_{tab\ (2,6)} > F_{cal}$) for the three different moisture regimes at different depths (Table 2). Sorptivity in the present study might be affected by tillage intensity and applied irrigation water. Sorptivity in the fields with higher levels of irrigation (irrigated cultivated fields) was 14-53% higher than in the less intensively irrigated plots (waterlogged fields). Irrigation increases total porosity and pore continuity. For this reason, sorptivity of irrigated cultivated fields in the present study might have been higher than that of the waterlogged fields, though the textural classes of both types of fields were similar (Bhattacharya *et al*., 2008).

The humic acid (HA) and fulvic acid (FA) fractions of soil organic matter are given in Table 3. Fractionation of organic matter showed that the percentage content of HA was the highest (0.35%) in the waterlogged soil, and that of FA was the lowest (0.1%) in the surface layer of the same soil. On the other hand, the FA fraction was the highest in the non-irrigated upland soil (0.2%). The irrigated cultivated soil showed intermediate values (0.12%). In the deeper layers also HA percentage content was higher in the waterlogged soil (0.30-00.29%). The HA/FA ratio decreased with depth (0.35-0.33 for non-irrigated upland soils and 3.5 to 3.2 for waterlogged soils).

The relationships between sorptivity and clay, pH, EC, porosity and humic acid were significant (at 1% probability level) (R = -0.86, -0.70, -0.94, -0.87 and -0.85, respectively), exponential and negative (Table 4). Percentage share of fulvic acid was positively correlated (R = 0.90, significant at 1% level) with sorptivity. Table 5 shows that both the percentage of clay content and clay + silt content were significantly (+ve) correlated to $C_{org.}$ ($R^2 = 0.75$ and 0.72, respectively). Humus is the major soil organic matter component, making up 75-80% of the total (Osat and Heidari, 2010). The humus content in alluvial soil is 1.5 -6% (Swift, 2011). The humic acid fulvic acid ratio in the present study was 0.35, 2.5 and 3.5 in the surface layers of the non-irrigated upland soil,

**Table 3**. Humic acid and fulvic acid content of soils (pooled data for three seasons)

| Soil | Depth (cm) | $C_{org.}$ | HA | FA | HA/FA ratio |
|---|---|---|---|---|---|
| | | | (%) | | |
| NIU | 0-15 | 0.68 | 0.07 | 0.20 | 0.35 |
| IC | | 1.93 | 0.30 | 0.12 | 2.50 |
| WL | | 1.68 | 0.35 | 0.10 | 3.50 |
| NIU | 15-30 | 0.61 | 0.06 | 0.18 | 0.33 |
| IC | | 1.24 | 0.30 | 0.11 | 2.70 |
| WL | | 1.26 | 0.30 | 0.09 | 3.30 |
| NIU | 30-45 | 0.59 | 0.06 | 0.18 | 0.33 |
| IC | | 0.92 | 0.25 | 0.09 | 2.70 |
| WL | | 0.96 | 0.29 | 0.09 | 3.20 |

Explanations as in Table 1.

**Table 4.** Relationship between soil chosen parameters and sorptivity (*S*)

| Soil parameter | Correlation coefficient (r) | Regression equation |
|---|---|---|
| Clay (%) | -0.86 ** | $S = 6.0\ e^{-0.02\text{-}x}$ |
| pH | -0.70 * | $S = 359.5\ e^{-0.87\text{-}x}$ |
| EC (dS $m^{-1}$) | -0.94 ** | $S = 18.2$ e -28.5-x |
| Porosity (vol.) | -0.87 ** | $S = 31.9\ e^{-4.5\text{-}x}$ |
| Humic acid (%) | -0.85 ** | $S = 4.3\ e^{-1.7\text{-}x}$ |
| Fulvic acid (%) | 0.90 ** | $S = 0.45\ e^{12.3\text{-}x}$ |

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

**Table 5.** Relation between organic carbon ($C_{org.}$) and clay, silt + clay

| Soil separates (x) | Square of correlation coefficient ($R^2$) | Regression equation |
|---|---|---|
| Clay (%) | 0.75* | $C_{org.} = 0.29 + 0.01$ x |
| Clay + silt (%) | 0.72* | $C_{org.} = 0.25 + 0.01$ x |

*significant at 5% probability level.

irrigated cultivated and waterlogged soils, and slightly decreased with soil depth (0.33, 2.7 and 3.2, respectively, in 30-45 cm layer) (Osat and Heidari, 2010; Weil, 1993). The presence of humic acid in soil generally decreases the volumetric water content of soil. Decline in water repellence of soil is due to the presence of watersoluble fulvic acid. The non-irrigated upland soils in the present study had a higher fraction of fulvic acid (0.15-0.2%), due to which they were more capable of infiltration, whereas waterlogged soils had a greater fraction of insoluble humic acid (0.29-0.35% ) and exhibited less cumulative infiltration (Dyke *et al*., 2009; Singh and Das, 1992) (Table 3). The sorptivity decreased as the clay content, pH, EC, porosity and humic acid content of the soil increased (R= -0.86, -0.70, -0.94, -0.87, and -0.85, respectively) (Table 4). Similar results were found by Singh and Kundu (2001 ) for Orissa (India) soils.

The clay content was found to be the best predictor of organic carbon. Table 5 shows that both the percentage of clay content and percentage of clay plus silt were significantly (+ve) correlated with the percentage of organic carbon ($R^2 = 0.75$ and 0.72, respectively). This may be attributed to 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 (Mtambanengwe *et al*., 2008).

## CONCLUSIONS

1. Cumulative infiltration and sorptivity showed that in general the values were high in non-irrigated upland soils and low in waterlogged soils, and intermediate in irrigated cultivated soils.

2. The non-irrigated upland soils had a higher fraction of fulvic acid, due to which they were more capable of infiltration, whereas the waterlogged soils had a greater fraction of insoluble humic acid and exhibited less cumulative infiltration, which might be partially contributing towards water congestion on the surface.

3. The humic acid fulvic acid ratio decreased with soil depth.

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

5. Physicochemical parameters like organic carbon, porosity, EC, pH *etc*. and sorptivities, studied in three different seasons, did not differ much indicating the influence of seasons on soil sorptivity was low. However, the correction of soil pH and EC, and modification of soil texture with adoption of appropriate amendments will help in improving the sorptivity of the soils.

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