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Soil Characteristics in relation to soil erosion and crop productivity in submontane Punjab

MS Hadda*, Vivek Pal Singh* and Sumita Chandel* and Narinder Mohan#

Abstract: *Physical, chemical, and morphological characteristics of soil are a prerequisite for efficient watershed management. The study was undertaken to evaluate physical, chemical, and morphological characteristics of Bhadiar micro-watershed in relation to soil erosion and crop productivity. The pedons were either structure less or massive. The soils were highly erodible. The infiltration rate was higher in middle and lower slope position than that in upper slope position. The soil pH increased with increase in soil depth whereas EC, organic carbon, available N, P and K decreased with increase in depth in all the pedons. Silt content in examined pedons decreased whereas sand and clay content increased. Aggregate content, water holding capacity, saturated hydraulic conductivity decreased with decrease in depth to lower layers of horizons. Bulk density increased with increase in depth. Maize yield reduced to 31.4 q ha*$^{-1}$ *at upper slope position from 38.5 q ha*$^{-1}$ *at lower slope position. The productivity index ranged from 0.08 to 0.30 in the pedons. The slope was found to be most significant factor in affecting the yield of maize crop followed by pH and calcium carbonate content. In the area, the water erosion, the distribution of water through rainfall and weathering interacts together and play a major role in affecting the soil texture of various slope positions and horizons. The relationships among organic matter content, runoff and sediment generation and transport needs to be investigated on different slope positions and transects. These relationships could help establish a link between easily measured topographic parameters and some specific soil properties needed to understand water flow along different slope positions which reduces time and cost of analysis.*

Key words: ***W****ater erosion, Horizons, Slope position, Soil erodibility, Productivity*

INTRODUCTION

Soil erosion is being increasingly recognised as a serious problem all over the world because of its potential threat to agricultural productivity and environment health. In submontane Punjab, soil erosion by water is a major cause of land degradation, which is one of the most degraded parts of Himalayan ecosystem. The area suffers from soil erosion due to indiscriminate human interference, undulating topography, climatic hazards, poor soil structure and high erodibility of soils (Kukal *et al.*,1993; Hadda *et al.*, 2002). Which leads to about 35-45 per cent runoff and 25-225 t ha^{-1} yr^{-1} soil loss (Sur and Ghuman 1992). Erosion reduces the overall productivity of terrestrial ecosystems in several ways. First, in order of importance, erosion increases water runoff, thereby decreasing water infiltration and the water-storage capacity of the soil, organic matter and essential plant nutrients are lost in the erosion process and soil depth is reduced. This will affect the soil biodiversity.

The magnitude of soil erosion and land degradation depends largely on different inherent soil properties (Singh & Prakash 2000). So, thorough understanding of soil physical parameters is essential for assessment of soil erosion and productivity for planning effective soil and water conservation programmes in the area. Soil erodibility can be related with various soil characteristics in the region. The suitability of soil for crop production is based on the quality of the soil physical, chemical and biological properties. One of the naturally occurring processes that detrimentally affect the soil properties and crop production is soil erosion. Keeping all points in view, the present study was conducted in the erosion-prone, fragile ecosystem to evaluate the soil physical, chemical and morphological characteristics of watershed in relation to erosion and crop

* Department of Soil Science, Punjab Agricultural University, Ludhiana
# National Institute of Rural Development New Delhi

productivity. Information on physical, chemical and morphological characteristics of watershed is a prerequisite for efficient management of erosion and relating these characteristics with crop productivity in the region. The present studywas thus planned with following objectives to evaluate the physical, chemical and morphological characteristics of the representative sites in the micro-watershed and to relate soil erosion and crop productivity with the soil characteristics

MATERIALS AND METHODS

Site description and soil sampling: The study was carried out in the Bhadiar micro-watershed located in block Garhshankar, district Hoshiarpur, situated at an altitude of 355 m above the mean sea level, having sub-humid type of climate as per classification of Thornthwaite (1948). The mean annual rainfall of the area is 1000 ± 150 mm. Out of the total rainfall, more than 80 per cent is received in the months of June to September (summer season) and remaining 20 per cent in October – March (winter season). The mean maximum temperature vary from 18.6 ^oC in January to 39.1 ^oC in May and mean minimum temperature varies from 5.2^oC in December to 24.7^oC in June. The majority of soils of the area are medium to coarse in texture with low to medium in moisture retention capacity. These soils are highly erodible. The soils of the area are represented by great groups of Haplustepts, Ustorthents, Ustipsamments and Haplustalfs (Kumar *et al*. 1995). Ten spots were randomly selected in a watershed and samples were collected. Six soil profiles were selected and soil samples were collected from each horizon.

Soil analysis

Soil bulk density (BD) was determined by the gravimetric method, while porosity was determined from bulk density and particle density. Other physical parameters like soil texture (international pipette method); size distribution of aggregates (wet sieving method, Yoder 1936); Hydraulic conductivity (constant head permeameter method, Klute 1965); infiltration rate (double metallic ring infiltrometer method, Richard 1954); maximum Water holding capacity (Keen's Box method) was also determined. Soil Chemical parameters like pH and EC (1:2 soil water suspension method, Jackson, 1973); organic carbon (wet digestion method; Walkley and Black, 1934); Cation exchange capacity (sodium acetate method, Richards, 1954); Calcium carbonate (Puri's method, 1930) available nitrogen (alkaline potassium permanganate method, Subbiah and Asija, 1956); available phosphorous (Olsen's method, Olsen *et al.* 1954); available K(neutral ammonium acetate method, Jackson 1973).

Soil erodibility indices

Soil erodibility index was calculated by using measured soil properties

Dispersion ratio

$$Dispersion\ ratio = \frac{\%\,(Silt + Clay)\ in\ undispersed\ soil}{\%\,(Silt + Clay)\ in\ dispersed\ soil}$$

Dispersion ratio was determined by using the approach of Middleton (1930)

Erosion ratio

Erosion ratio was calculated as described by Middleton (1930)

$$Erosion\ ratio = \frac{Dispersion\ ratio}{\%\,Clay / Moisture\ equivalent}$$

Moisture equivalent (ME)

It is expressed in per cent as follows:

ME = ½ × (MWHC).

Where, ME is moisture equivalent in cm and MWHC is the maximum water holding capacity

Clay ratio

Clay ratio was calculated as described by Bouyoucos (1935)

$$Clay\ ratio = \frac{\%\,(Sand + Silt)}{\%\,Clay}$$

Erosion-productivity relationship

Regression equation was employed to relate yields of maize crop grown in the area with percent clay, percent sand, calcium (meq/100 gm soil), surface soil thickness in cm of A_1 horizon, solum thickness (A & B or A & C horizons in cm), pH and slope in percent.

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_2^2 + B_5X_3^2 + B_6X_4 + B_7X_5 + B_8X_6 + B_9X_7 +$$

Where, Y is yield of crop in q ha^{-1}, B_0 is the intercept on the Y- axis, X_1 is percent soil slope; X_2 is percent clay; X_3 is percent sand; X_2^2 is quadratic effect of clay; X_3^2 is quadratic effect of sand; X_4 is calcium content in meq/100 gm of soil; X_5 is surface thickness of A horizon in cm; X_6 solum thickness of A & B horizons in cm; X_7 is pH and e is lack of fit associated with Y, which will be assumed to be a random error.

Productivity index

The approach of Pierce *et al*. (1983) is used for computing Productivity Index (PI) in gm cm^2. It can be expressed as:

$$PI = \Sigma^{r}_{i=1} (A_i \times C_i \times D_i \times WF)$$

Where,

PI is soil productivity index, A_i is sufficiency of available water capacity in cm cm^{-1},C_1 is sufficiency of bulk density in g cm^{-3}, D_1sufficiency of pH, WF is weighting factor and r is the no. of horizons in rooting depth.

Sufficiency of available water capacity (A_1)

It is computed as follows:

$$C_w = \frac{M_{sm} - M_s}{M_s}$$

$A_i = C_w \times D_b$

Where,

C_w is mass water content, M_{sm} is mass of wet soil, M_s is mass of dry soil and D_b is bulk density in g cm^{-3}.

Computation of sufficiency of bulk density (C_i)

$C_i = 0.826 \times D_{bc}$

Where, D_{bc} is critical bulk density in g cm^{-3} and is calculated as follows:

$$D_{bc} = \left(\frac{100 - 1.2 \times f}{100}\right) D_p$$

Where, f is porosity in percent and D_p is particle density in g cm^{-3}.

Computation of sufficiency of pH(D_1)

It is calculated with the following equation.

$D_i = 1.0$ for pH > 5.5

Computation of weighting factor (WF)

$$WF = 0.350 - 0.152 \log \left(D + \sqrt{D^2 + 6.45}\right))$$

Where, D is depth of each horizon in cm.

RESULTS AND DISCUSSION

Morphological characteristics

The colour of the studied pedons was in various shades of brown and the texture of studied pedons varied from loamy sand to sandy loam. Subsurface soils of all the pedons were sandy loam to sand. The structure of the pedons was either structure less or massive. The root distribution was deep. There was no root restricting feature and no lithic contact in the profile. The boundaries of horizons were mostly clear, irregular and occasionally diffused and smooth to wavy indicating erosional or sedimentation disturbance to the evolution of soil profiles.

Physical charactersics

The bulk density of all the soils in surface horizon varied from 1.35 to 1.51 Mg m^{-3} whereas in the sub-surface horizons, bulk density values ranged from 1.52 to 1.78 Mg m^{-3} (Fig 1). In all the pedons, the bulk density was observed to be increasing with depth. This may be due to the low organic matter content in the lower layers. The MWD varied between 0.42 to 0.52 mm for surface soils and from 0.37 to0.61 mm for sub-surface soils in the pedons (Fig 1). The low values of MWD generally reflect poor structural stability of these soils. As this area experiences medium to high intensity rainstorm during monsoon period, the soils are highly susceptible to soil erosion. Kolarkar *et al*. (1974) also observed a significant and positive correlation between clay content and aggregation. The available water holding capacity varied from 22.4 to 31.3 percent in surface horizon and from 14.6 to 28.3 percent in sub-surface horizon in different pedons (Fig 1). The water holding capacity decreases with soil depth. It was positively and significantly correlated (r = 0.52) with mean weight diameter. The total sand, silt and clay content in these soils varied from 57.2 to 90.0 percent, 3.6 to 23.6 and 6.4 to 19.6 percent, respectively. Sand, silt and clay contents followed irregular trends in all the pedons. This indicates that the pedons are still experiencing weathering. The distribution of silt fraction indicated that the silt content for most cases, increased toward the soil surface. This may be attributed to more leaching of clay at lower slope and accumulation of eroded sediments (mainly silt and clay) at these positions from runoff water.

CHEMICAL PROPERTIES

The soil pH was slightly alkaline in nature in all the pedons. (Fig. 2) The surface soil pH of all the pedons varied from 7.3 to 8.1 and pH of sub-surface soil varied from 7.9 to 8.4. The soil pH of lower depth varied from 8.2 to 8.7. The pH of soils is increasing with depth. This is due to leaching of bases from the surface horizons. Similar trends of results have been reported earlier in the area (Sharma *et al* 1998). The

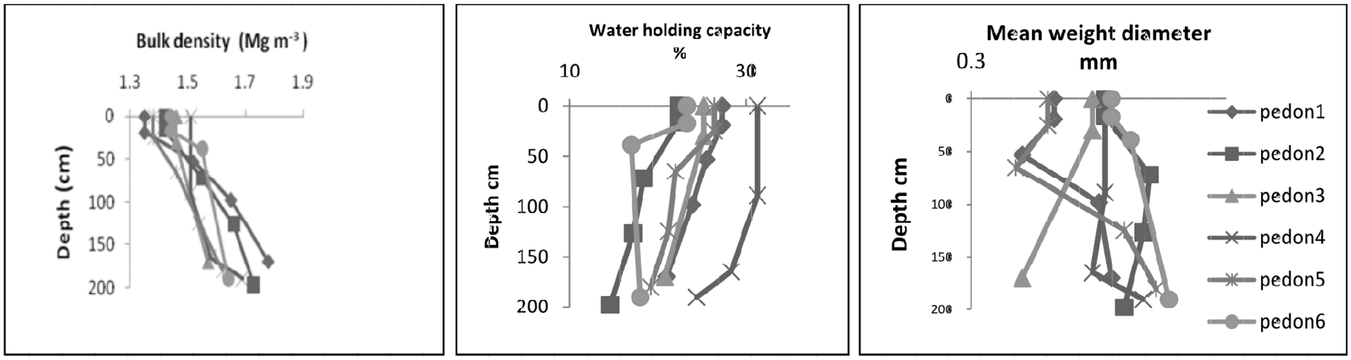

Figure 1: Depth wise distribution of Bulk density, water holding capacity and mean weight diameter indifferent pedons

electrical conductivity of 1:2 soil – water extract of all the studied soils varied between 0.08 to 0.23 dSm^{-1} (Fig. 2). Soils are non-saline in nature. It was observed that electrical conductivity values were higher at the surface and sub-surface horizons than that in lower layers. This may be attributed to upward movement of the soluble salts to the surface through the capillary rise of water under ustic soil moisture regime. Similar results have been also reported by Singh and Sahni (1974). Organic carbon in these soils varied from 0.04 to 0.21 per cent. It ranged from 0.16 to 0.21 per cent in surface horizon and from 0.10 to 0.18 per cent in sub-surface and from 0.04 to 0.10per cent in lower layers of soil(Fig 2). In general the organic carbon content decreased with depth indicating absence of fluventic deposits in the recent past as also pedoturbation. Chiacek and Swan 1994 also reported decrease in organic carbon content of soil with increase in soil depth in erosion affected areas. The organic carbon content of the soils were low due to high rate of decomposition of organic material under prevailing semi-arid climate in the area (Kukal 1987).

Calcium carbonate content in soils varied from 1.6 to 3.7percent (Fig. 3). Its presence is however, low and could be attributed to parent materials. The wide spread presence of calcareous parent materials in Shiwalik hills has been documentedby Kumar *et al* (1995). The cation exchange capacity showed wide variations among the studied pedons, the value of CEC varied from 4.5 to 14.2 cmol (p^{+}) kg^{-1} (Fig 3). Available nitrogen ranged from 56.2 to 106.5 kg ha^{-1}. In surface layer available nitrogen ranged from 87.7 to 106.5 kg ha^{-1} and in subsurface it ranged between 74.4 to 101.3 kg ha^{-1} (Fig 3). The available nitrogen content decreased with increase in soil depth. This could be because of the activity of nitrifying bacteria which is known to decrease with depth. The available phosphorus varied from 2.94 to 8.43 kg ha^{-1} (Fig 3). It was higher in surface horizons than that in sub-surface horizons. This could be associated with calcium carbonate and soil pH. Also, the $CaCO_3$ is well known for phosphorus fixation. There is sharp decrease in available phosphorus content in soils due to soil erosion (Stone *et al.* 1985). The potassium content of soil varied from 142.9 to 363.9 kg ha^{-1} (Fig. 3). The potassium content in all the pedons were medium to high. The available potassium in surface soils ranged from 230.4 to 363.9 kg ha^{-1} and in sub-surface it varied from 185.9 to 36.1kg ha^{-1}. The available potassium content decreased with increase in soil depth. Coarse texture and low organic carbon content might be responsible for medium value of available potassium.

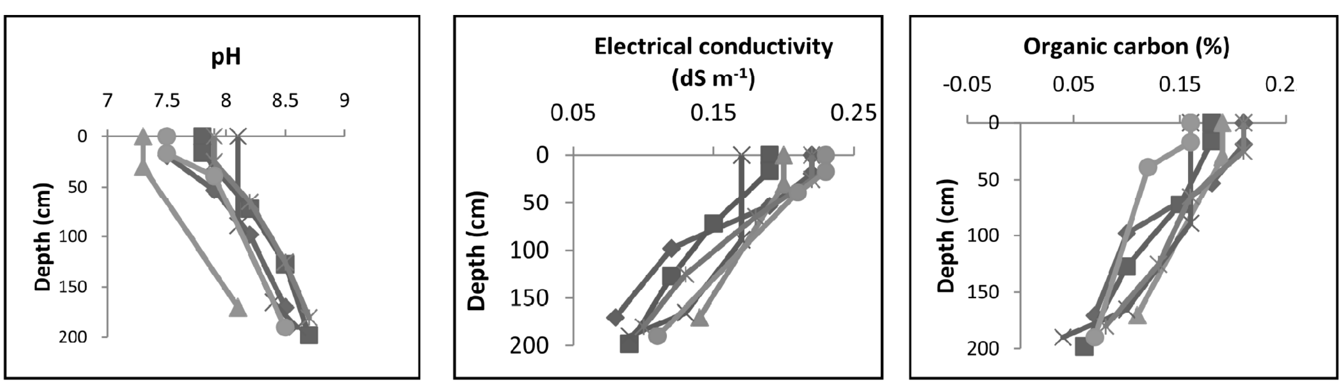

Figure 2: Depth wise distribution ofpH, electrical conductivity organic carbon indifferent pedons

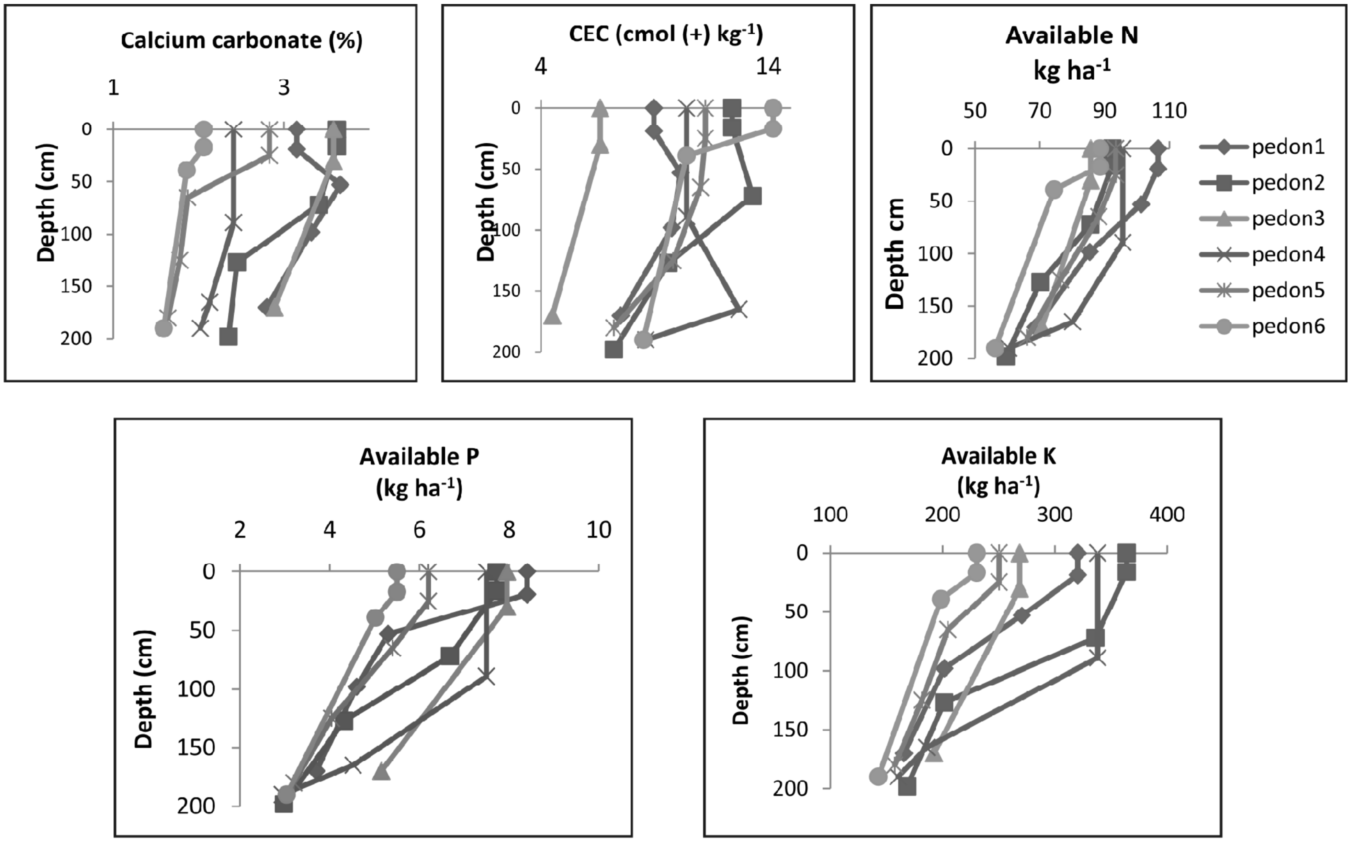

Figure 3: Depth wise distribution ofcalcium carbonate, cation exchange capacity, available N, P and K indifferent pedons

Changes in pedon chemical characteristics

The soil pH increased with increase in soil depth in all the pedons whereas EC, OC, available N, P and K decreased with increase in depth of horizons in all the pedons. This can be explained with 'R^2' values varying from 93.4, 66.5, 65.2, 67.3, 46.0 and 99.3 per cent respectively (Table 1). Decrease in organic carbon with increase in depth of horizons indicate that the original A horizon is in the process of partial removal which is major factor affecting sustainability of agricultural systems (Blair *et al.* 1995). The $CaCO_3$ contents (R^2 = 51.4 per cent) which is consistent with depth of horizons viz 21.2 to 138.9 cm. The amount of calcium carbonate concretion is dominant factor responsible for lowering the productivity of soils in the area. Observations indicate that changes in the clay and low organic matter contents at the surface horizons contributed to increased surface sealing, curst formation and runoff. These processes decreased the productivity of soils due to erosion which directly affects the germination rates and seedling emergence. The decrease in aggragate content, water holding capacity and increase in bulk density with increase in depth of root horizons and presence of $CaCO_3$content in horizons is the major yield limiting factor related with erosion of the soils.

Changes in pedon physical characteristics

The silt content in all the pedons decreased whereas sand and clay content increased. The 'R^2' values varied from 6.6 to 17.2 percent in these parameters (Table 2). This may be due to removal of the high silt surface horizons, accumulation of relatively dense sand sized materials at the surface as the smaller and less dense materials are removed by erosion through the transportation and gradual incorporation of clay rich materials in the surface horizons by cultivation and profile thickness decreases. Rhoton and Tyler (1990) obtained similar kinds of results in the properties of fragipan soils at Missippi and West Tennesse, USA. Organic carbon decreased in all the pedons with depth. Aggregate content, water holding capacity, saturated hydraulic conductivity decreased with decrease in depth to layers of horizons explaining 11.8, 68.2 and 71.8 per cent (Table 2) of the variability respectively. However, in all the horizons, with increase in depth, there is increase in bulk density and decline in organic matter content.

Table 1
Statistical parameters determined for the relationship between soil chemical properties of surface and subsurface depths

Soil Property	*Units*	*Statistical Parameters*	*Depth of Horizons (cm)*			*Regression Equation*	*R^2*
			21.16	62.5	138.92		
pH		Mean	7.6	8.1	8.4	Y=3.168+0.670X	0.934*
		Range	7.3-7.9	7.9-8.2	7.9-8.7		
		S.D.	0.22	0.21	0.18		
Electrical Conductivity	dS m^{-1}	Mean	0.21	0.17	0.13	Y=-0.012+0.716X	0.665**
		Range	0.19-0.23	0.15-0.19	0.10-0.21		
		S.D.	0.015	0.028	0.025		
Organic Carbon	%	Mean	0.19	0.17	0.10	Y=0.023+0.444X	0.652**
		Range	0.16-0.21	0.15-0.18	0.04-0.16		
		S.D.	0.019	0.021	0.016		
Calcium Carbonate	%	Mean	3.08	3.54	2.34	Y=0.013+0.784X	0.514**
		Range	2.06-3.62	3.41-3.66	1.59-3.32		
		S.D.	0.58	0.18	0.56		
CEC	Cmol kg^{-1}	Mean	11.1	11.72	8.48	Y=1.716+0.640X	0.700**
		Range	6.6-13.26	10.13-13.13	4.5-11.01		
		S.D.	2.86	2.24	2.09		
Available N	Kg ha^{-1}	Mean	95.7	93.5	72.2	Y=6.994+0.721X	0.673**
		Range	85.7-107.5	85.6-101.3	56.2-95.6		
		S.D.	9.19	11.1	6.18		
Available P	Kg ha^{-1}	Mean	7.6	6.1	4.1	Y=1.197+0.410X	0.460
		Range	5.57-9.98	5.32-6.68	0.42-7.49		
		S.D.	1.58	1.10	0.95		
Available K	Kg ha^{-1}	Mean	298.7	303.3	190.2	Y=67.25+0.455X	0.993*
		Range	230.4-363.9	270.5-336.1	142.9-204.7		
		S.D.	56.98	46.39	19.86		

* Significant at 5 % level
**Significant at 10% level

Table 2
Statistical parameters determined for the relationship between soil physical properties of surface and subsurface depth

Soil Property	*Units*	*Statistical Parameters*	*Depth of Horizons (cm)*			*Regression Equation*	R^2
			21.16	*62.5*	*138.92*		
Bulk Density	Mg m^{-3}	Mean	1.42	1.54	1.62	Y=1.670-0.056X	0.006
		Range	1.35-1.46	1.52-1.55	1.46-1.78		
		S.D.	0.043	0.021	0.070		
Aggregation (MWD)	Mm	Mean	0.47	0.48	0.51	Y=-0.219+0.600X	0.118
		Range	0.42-0.52	0.38-0.58	0.38-0.61		
		S.D.	0.041	0.14	0.069		
Water Holding Capacity	%	Mean	26.37	21.96	19.55	Y=-9.848+1.126X	0.682**
		Range	22.42-33.523	18.36-25.56	12.63-31.32		
		S.D.	3.96	5.09	5.38		
Saturated Hydraulic Conductivity 0.718**		Cm min^{-1}	Mean	4.62	5.16	4.38	Y=-0.085+1.078X
		Range	4.02-5.28	4.68-5.64	3.54-5.34		
		S.D.	0.50	0.11	0.095		
Sand	%	Mean	77	77.3	78.41	Y=90.1-0.158X	0.020
		Range	71.6-85.6	75.2-79.4	57.2-83.8		
		S.D.	5.72	2.97	6.54		
Silt	%	Mean	12.5	11.7	10	Y=16.67-0.488X	0.172
		Range	6.5-15	10-13.4	3.6-23.6		
		S.D.	3.54	2.40	4.34		
Clay	%	Mean	11.4	11	11.36	Y=16.81-0.465X	0.066
		Range	9-13.6	10.6-11.4	6.4-19.6		
		S.D.	1.46	0.57	2.93		

**Significant at 10% level

Table 3
Depth distribution of soil erodibility indices of water erosion

Horizon	*Depth (cm)*	*Dispersion ratio*	*Erosion ratio*	*Clay ratio*	*Silt/Clay ratio*	*Clay/M.E. ratio*
			Per cent			
			Pedon 1			
A	0-19	44	52	7.77	1.17	0.84
AC	19-53	38	46	8.43	0.94	0.83
C_{11}	53-98	25	24	7.19	0.62	1.03
C_{12}	98-170	24	23	7.92	0.45	1.07
			Pedon 2			
A	0-16	33	27	6.35	1.09	1.21
AC	16-72	28	23	7.77	1.17	1.24
C_{11}	72-127	31	36	12.51	1.67	0.86
C_{12}	127-198	25	23	11.82	1.15	1.07

Table 4
Depth distribution of soil erodibility indices of water erosion

Horizon	*Depth (cm)*	*Dispersion ratio*	*Erosion ratio*	*Clay ratio*	*Silt/Clay ratio*	*Clay/M.E. ratio*
			Per cent			
			Pedon 3			
A	0-30	26	28	7.62	1.29	0.92
C	30-170	36	24	5.33	0.70	1.52
			Pedon 4			
C_1	0-89	28	39	7.93	0.77	0.72
C_2	89-165	53	67	7.93	0.45	0.79
C_3	165-190	47	56	9.00	0.36	0.83

Table 5
Depth distribution of soil erodibility indices of water erosion

Horizon	*Depth (cm)*	*Dispersion ratio*	*Erosion ratio*	*Clay ratio*	*Silt/Clay ratio*	*Clay/M.E. ratio*
			Per cent			
			Pedon 5			
A	0-25	22	26	8.38	0.55	0.85
A_{11}	25-65	28	25	7.69	0.37	1.13
C_{12}	65-125	52	38	5.31	1.64	1.36
C_2	125-180	43	21	3.92	1.18	2.04
			Pedon 6			
A	0-17	57	57	7.33	1.29	1.00
C_1	17-39	27	20	7.60	1.18	1.34
C_2	39-190	33	46	15.06	0.56	0.71

Table 6
Weighted means of chemical characteristics of the soils at upper and lower slope position

Soil Depth (cm)	*pH*	*Electrical Conductivity ($dS\ m^{-1}$)*	*Organic Carbon*	*Calcium carbonate*	*Cation exchange capacity*	*Available Nitrogen*	*Available Phosphours*	*Available Potassium*	*Maize yield q ha^{-1}*
			Per cent				*kg ha^{-1}*		
				UPPER SLOPE POSITION					
0-15	8.1	0.19	0.68	2.8	5.4	84.3	6.1	82.2	30.4
15-30	8.5	0.15	0.39	1.8	4.2	65.3	4.1	58.5	
				LOWER SLOPE POSITION					
0-15	7.8	0.16	0.71	3.0	8.5	90.2	7.2	90.5	39.1
15-30	8.2	0.12	0.44	2.7	5.9	78.2	5.2	98.6	

Table 7
Weighted means of Physical characteristics of the soils at upper and lower slope position

Soil Depth (cm)	*Bulk Density (Mg m^{-3})*	*Mean Weight Diameter (mm)*	*Maximum Water holding capacity*	*Moisture equivalent*	*Saturated hydraulic conductivity (cmh^{-1})*	*Plant available water in soil*	*Sand*	*Silt*	*Clay*
			Per cent				*Per cent*		
				UPPER SLOPE POSITION					
0-15	1.55	0.39	35.23	17.61	3.7	5.01	55.6	22.1	22.3
15-30	1.62	0.37	22.45	11.22	3.3	4.91	65.5	13.7	14.8
				LOWER SLOPE POSITION					
0-15	1.39	0.44	25.21	12.60	4.0	10.11	53.7	21.5	24.8
15-30	1.48	0.41	21.34	10.67	3.4	8.72	59.5	20.1	20.4

Infiltration rate

The infiltration rate was observed to be lower by 10 and 30 per cent in middle and lower slope position as compared with upper slope position for first 2 minutes. But in the lapse of further 15 minutes, the infiltration rate was observed to be lower by 20 per cent and 28 per cent on middle and lower slope position than that of upper slope position. The large differences observed in the infiltration rate, in first 5-25 minutes may be attributed due to the presence of more organic matter content in surface layers over the sub-surface layers.The steep decline in infiltration rate in further 5-30 minutes onwards is as per the expectations because of increase in wetted length of hydraulic gradient with time. It was observed that lower slope position showed less infiltration rate than that within upper slope position. This may be due to the presence of more clay content in lower slope position over the upper slope position. Bradford *et al* (1987) revealed that reduction in infiltration rate might be due to seal formation but the extent of seal formation depends upon the texture and porosity of soils.

Soil erodibility indices

The depth distribution of different soil erodibility induces viz. Dispersion ratio, erosion ratio, clay ratio, clay /moisture equivalent and silt/clay ratio of all pedons is presented in Tables 3,4 and 5. The per cent dispersion ratio ranged from 22 to 57 in surface and from 24 to 53 in sub-surface horizons. The percent erosion ratio values ranged from 26 to 57 in surface and 20 to 76 in sub-surface horizons.According to Middleton (1930), soils with erosion ratio greater than 15 and dispersion ratio greater than 10 were considered as erodible. Therefore, the soils of studied pedons were erodible in nature. It is also indicated by the high values of clay ratio and clay/moisture equivalent ratio's. Also, sub-surface soils were found to be more erodible than those surface soils because of high value of erosion and dispersion ratio.

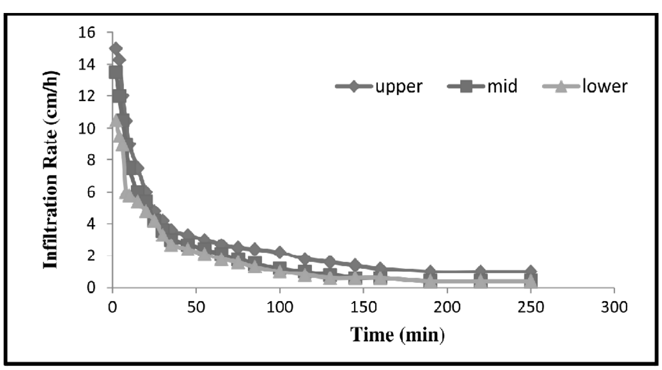

Figure 4: Infiltration rate as a function of time for different slope positions at Bhadiar

Soil physical and chemical characteristics in upper versus lower slope position

The loss of soil by erosion in upper slope position which resulted in loss of plant nutrients and thereby affecting soil productivity. From the Tables 6-7, it is apparent that upper slope soils which suffer from high degree of erosion has higher bulk density, electrical conductivity but lower calcium carbonate, Organic carbon, cation exchange capacity, available N, P and K, mean weight diameter, saturated hydraulic conductivity and plant available soil water than the soils at lower slope position. Cation exchange capacity of upper slope position decreased by 36 per cent due to corresponding decrease in clay content with erosion. Available nitrogen, phosphorus and potassium in upper soils than that in soils at lower slope position were less due to reduction in organic carbon and increase in pH respectively. Mean yield of maize at upper slope position reduced to 31.4 q ha^{-1} from 38.5 q ha^{-1} at lower slope position due to adverse changes in major physical and chemical characteristics of soils. Yield reduction of maize may be due to decrease in plant available water in upper slope position than that in lower slope position however, the less plant available water causes more frequent and severe water stress to crops.

Erosion productivity relation

Maize grain yield (Y) as function of per cent slope (X_1), clay (X_2), sand (X_3), calcium content (X_4), surface thickness of A-horizon (X_5), and profile thickness of A & C horizons (X_6) and pH (X_7) is expressed in the form of below mentioned equation :

$$Y = 62.572-7.351X_1+0.076X_2+0.040X_3 -0.799X_4 -0.051X_5+0.035X_6-1.241X_7$$

Mean maize yield index = 34.8 q/ha

The different parameters of the equation explained 96.5 per cent variation in the maize grain yield ($R^2 = 0.96$). The percent slope was found to be most significant factor in affecting the yield of maize crop followed by pH and calcium carbonate content. Hadda and Bhardwaj (2004) employed the above equation that explained 90 per cent of variation in maize yield at Ballowal Saunkhari, Nawanshahr. The regression coefficients have negative effect except calcium content and surface thickness of A-horizon which have positive effect on maize (*zea mays*) grain yield.

Productivity index

The Productivity index (PI) ranged from 0.08 to 0.30 in the pedons (Table 8). The higher value of PI indicates a higher capacity to produce crops and lower value of PI indicates lower capacity to produce crops. In all the pedons, the PI followed the order: P1>P2>P6>P5>P3>P4. The pedon 1 showed the highest value of PI due to high value of sufficiency of available water capacity and rooting depth. The increase or decrease in the sufficiency of available water capacity (AWC) and rooting depth (WF) are mainly responsible for increase or decrease in productivity index of the soils. Hadda and Bhardwaj (2004) employed empirical and parametric approaches to study soil productivity loss through soil erosion at zonal research station for kandi area (ZRSKA), Ballowal Saunkhari, Nawanshahr. Similarly, the PI ranged in the area from 0.18 to 0.89 for the examined pedons. Lower PI values of soils at higher slope position than that at lower slope position indicated that soil erosion by water resulted in loss of soil productivity. Lal (1984) used the parametric model for several soils in Nigeria and observed that inspite of the modification made in sufficiency values there were significant differences in observed yield versus computed productivity index values. The relationship obtained in the yield and productivity index at ZRSKA, Ballowal Saunkhari is poor ($R^2 = 0.50$). This implies that the factors considered in parametric model to compute Productivity index partially explains the variation in the crop productivity. So, there is a need to consider other factors which needs to be incorporated in the proposed parametric model and it requires further modification.

Table 8
Productivity index of Bhadiar micro-watershed

Pedon	*Productivity Index (PI=Ai×Ci×Di×WFi)*
P1	0.30
P2	0.28
P3	0.10
P4	0.08
P5	0.13
P6	0.14

Where Ai is sufficiency of available water capacity in $cmcm^{-1}$; Ci is sufficiency of bulk density in Mgm^{-2}; Di is sufficiency of pH; WFi is weighted factor in cm

CONCLUSION

The interactions exist between land use, the characteristics of slope position and soils, helps to controls runoff, sediment generation and transport, infiltration and organic matter content. These, consequently influences the soil moisture distribution and eventually soil physical properties and their variation. These relationships could help establish a link between easily measured topographic parameters and some specific soil properties needed to understand water flow along different slope positions, which reduces the time and cost of analysis.

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