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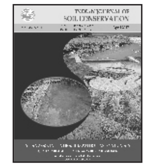

Assessment of productivity potential of some soils of Aravali hills based on parametric approach

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ABSTRACT

Six representative soil profiles were collected from different landform units of ER upland to assess land productivity index based on parametric approach. Soils, developed on different physiographic units *viz.*, hill, pediments, valley, very gently sloping, nearly level plains were studied for their characterization, classification and potentiality evaluation. Morphologically soils showed considerable color variations with dominant hue of 10YR. The sand, silt and clay content in soils of ER upland ranged from 8.10 to 53.87%, 28.73 to 45.67% and 16.07 to 49.75%, respectively. The Bulk density showed increasing trend with the depth and varied from 1.43 to 1.68 Mg M^{-3}. Soils on valley and plains were well developed as compared to those on hill and pediments. The soils are classified as lithic Ustorthents (P_1 and P_2), Typic Haplustepts (P_3, P_4 and P_5) and Typic Haplusterts (P_6). The productivity of hill and pediments soils was extremely poor for crop (1.57%), pasture (5.89%) and tree (0.12%). Agriculture productivity of valley, pediments and plains (P_3 -29.43%, P_4 -31.07%, P_5 -27.62% and P_6 -31.07%) was assessed as average. With adoption of improved package of practices like moisture conservation, addition of organic manures *etc.,* the productivity class of these soils can be upgraded to good (from 50.40 to 53.87%). The potentiality of ER upland soils for crop, pasture and commercial crops production can be improved as indicated by coefficient of improvement (varied from 0.93 to 5.23%). The soils on Sawantgarh series (P_4) and Raitoda series (P_6) had the highest potentiality for crop and pasture production.

Key words:
Aravali,
ER upland,
Land productivity,
Land potentiality,
Topography,
Transect

1. INTRODUCTION

Agriculture is one of the world's most important activities supporting human life. Potential land use assessment is likely to the prediction of land potential for productive land use types (Dadhwal *et al.*, 2011). The landforms comprise geomorphological units and are largely defined by surface forms and location in the landscape (Gessler *et al.,* 1995; Park and Burt 2002; Mini *et al.* 2007). Land productivity capacity or land quality is a comprehension, at the same time a precise concept in terms of agricultural activities (Dengiz and Saglam, 2012). The land quality can be defined as "the condition and capacity of land, including its soil, climate, topography and biological properties, for the purpose of production, conservation, and environmental management" (Pieri *et al.,* 1995) or simply the capability of land to perform specific functions (Devi and Kumar, 2008). Undoubtedly, one of the ways to provide food is to increase production in area and to use the land with respect to its potentiality in an appropriate way. The land productive capacity can be evaluated directly or indirectly. Direct evaluations are carried out in the field, greenhouses or laboratory by means of some experiments under given climatic and management conditions. Indirect evaluations basically consist the developing and applying models of varying complexity, thereby attempting to estimate land productivity (Dengiz *et al.,* 2010).

Soil-landform studies are important to explore the relationship between soil properties and landforms. Such studies enable to extrapolate the soil properties on similar land forms under the same overhead climatic condition and thereby reduce time and efforts in soil resource management (Karmakar, 2014). This is because of a land form unit is formed by the same geomorphic processes that are responsible for providing the substrate material of the soils. The land quality assessment helps in to determine the yield controlling factors across sites and their spatial distribution (Abrol *et al.,* 2015). This also provides a fair opportunity of matching between input resources and yield determining factors so as to maximize plant performance and minimize off site environmental effects (Meena *et al.,* 2014). Brubaker *et al.* (1993) studied soil properties in relation to landform positions and found significant differences among soil properties like sand, silt, pH and exchangeable cations. The soils on relatively unstable landforms indicated young and immature A-C profiles whereas, those from stable landforms showed distinct profile development.

Soils on different physiographic units have been studied by Mehta *et al.* (1962) across Bundi district of Rajasthan but such studies are very meager in Eastern Rajasthan Upland (ER upland). The topography of ER upland is moderate to highly undulating with a number of scattered rock outcrops. The geology of the study area is quite complex and Aravali series plays an important role in the rock formation. The Aravalli hills are the remnant of a great mountain range which millions of years ago rivaled the Himalayas. The range is represented by (i) a basal quartzite formation often conglomeratic; (ii) an impure carbonate unit generally dolomitic in composition; and (iii) an argillaceous formation consisting of slaty, phyllitic and micaceous schistose types. The catenas with rock outcrops and without rock outcrop and without plinthite are more widespread in ER upland. The careful planning of the use of land resources should be based on land potential evaluation. The present study emphasizes on characterization and potentiality aspects of the soils of ER upland in relation to different landform units. The study is of great importance in ascertaining that which uncultivated land can be brought into production and which cultivated soils could produce more than at present with guiding decisions on land uses in terms of potential and conserving natural resources in ER upland. The present investigation is assist in to determine the agricultural utility of the soils and their susceptibility to improvement in relation to soil properties. The aim of this study is to determine specific capabilities, most appropriate use and potentiality of ER Upland soils under specific management practices.

2. MATERIALS AND METHODS

Study Area

The irregular rhombus territory of the district is traversed by a double line of hills from south-west to north-east direction throughout it whole length. Bundi district covers an area of 5850.50 km^2 and constitutes of two physiographic landforms *i.e.* ER upland and Vindhyan Landscape which represents 40.5 and 59.5% of total geographical area of the district, respectively. Geographically the district is defined by 75°19'30" to 76°19'30"E longitude and 24°59'11" to 25°53'11"N latitude in Rajasthan state of Western India. District comprises of different land form units such as hill, pediments, valley, plain (very gently to nearly gently sloping) and nearly level plain. The study area covers a transect *i.e.* ER upland in Bundi district of South-Western Rajasthan. The net cropped area of the district is 254 km^2 with cropping intensity of 159%. The area is characterized by semi-arid subtropical climate. Monthly normal climatic characters of Bundi district are presented in Table 1. Annual rainfall is about 761 mm with July and August being the wettest months. Almost 96% of annual rainfall is received in the four monsoon months. On an average, there are about 35 rainy days with rainfall of above 2.5 mm day^{-1}. Mean annual Potential Evapo-Transpiration (PET) is 1036.6 mm and Length of Growing Period (LGP) is 90-120 days with water deficits in seven to eight months. The mean annual temperature is 25.8°C with annual maximum and minimum of 33.02°C and 18.62°C, respectively. The MWST and MSST is greater than 5°C. The area qualifies for Ustic soil moisture regime and hyperthermic temperature regime.

A series of detached hills and ridges in northern side is the distinguishing feature of ER upland. The western portion of ER upland is occupied by schists belonging to the Aravali system. At the capital, sandstones of the upper Vindhyan age are faulted down against the Aravalli schists (Mehta *et. al*., 1962). The plain region is intercepted by scattered hillocks and rocky outcrops. The northeastern side soils of ER upland are deep while northwestern side soils are comparatively shallower. The whole area is intercepted by occasional water courses and two important seasonal rivers

Table: 1
Climatic characters of Bundi district (average of 1951-80)#

Element	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual mean
Max.T (°C)	24.5	28.5	34.1	39.0	42.6	40.3	33.3	31.7	33.1	34.5	30.8	26.7	33.3
Min.T (°C)	10.6	13.1	18.5	24.4	29.7	29.5	26.4	25.4	24.7	21.0	14.8	11.3	20.8
Rainfall (mm)	5.4	3.4	3.2	2.5	7.2	67.6	281.0	273.5	106.2	7.8	2.1	0.9	760.8*
Rainy days	0.6	0.5	0.4	0.3	0.7	4.0	11.8	10.9	5.3	0.5	0.2	0.1	35.4*

#Data taken from project "Rural Prosperity through Integrated Watershed Management: A Case Study of Gokulpura-Goverdhanpura in Eastern Rajasthan" report (Pathak *et al.*, 2007) ; *Rainfall and rainy days are total for the year.

i.e. Mez and Mangli which drains into the Chambal river. The distribution of natural vegetation over the study area is near about same and dominant species are Neem (*Azadirachta indica*), Babul (*A. nilotica*), Sheesham (*D. sissoo*), Peepal (*P. religeosa*), Mango (*M. indica*), Bamboo (*B. tuida*), Ber (*Zizyphus sp.*) Khair (*A. chundra*), Subabul (*L. leucocephala*), Palas (*B. monosperma*), Khejri (*P. cineraria*) and grasses (*C. dactylon*, *C. ciliaris, D. annulatum etc.*).

Six soil profiles were collected representing Lithic Ustorthents (P_1-Umar series- Hill), Lithic Ustorthents (P_2-Sela ka data series-Pedimont), Typic Haplustepts (P_3-Khatwada series-Valley), Typic Haplustepts (P_4-Sawantgarh series- Very gently sloping), Typic Haplustepts (P_5-Kanwar series- Nearly level plains-I) and Typic Haplusterts (P_6-Raitoda series- Nearly level plains-II). Location, site characteristics of soil profiles, soil classification and soil physiographic relationships of profiles are presented in Table 2 and Fig. 1 and Fig. 2.

Soil Sampling and Analysis

The physiographic map (1:50,000) was used as a base map and a transect *i.e.* ER upland which covers major land form units was selected for the study. Morphological features of the profiles were studied in the field as per Soil Survey Manual of IARI. A stratified purposive sampling procedure was adopted. Six pedons representing change in geomorphology, topographic gradient and soil characteristics of various landforms were excavated (Fig. 2). For each position three to four profiles were sampled as replicates. The color of soil in field was determined with help of Munsell color chart. Undisturbed core samples (7.5 x 8.0 cm) from each horizon were also collected for determination of physical properties like bulk density. The samples were air dried and gently crushed with a wooden mortar pastel and passed through 2 mm sieve. A part of soil samples (sub-sample) was grounded to pass through 0.5 mm sieve. Samples were treated with 35% H_2O_2 to destroy organic matter and with calogon (sodium hexametaphosphate) to

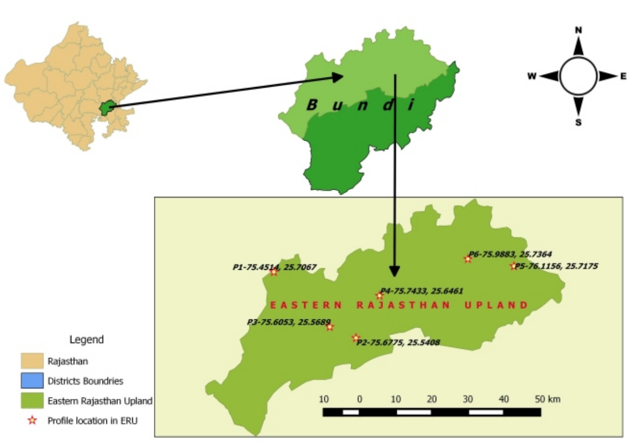

Fig. 1. Location map of eastern Rajasthan upland and representing pedons in Bundi district of Rajasthan, India

Table: 2
Site characteristics, diagnostic criteria and classification of soils of Eastern Rajasthan upland

Pedons and Landforms type	Series Name	Location	Slope %	Order	Suborder	Great group	Subgroup	Family*
Eastern Rajasthan Upland								
P_1 (Hill)	Umar	25^{0}42'24" N 75^{0}27'05" E	8-20	No horizon development (*Entisols*)[$]	Other Entisols (*Orthents*)	Ustic moisture regime (*Ustorthents*)	Lithic contact depth < 50 cm (*Lithic ustorthents*)	Loamy skeletal mixed hyper thermic
P_2 (Pediments)	Sela Ka Data	25^{0}32'27" N 75^{0}40'39" E	8-15	No horizon development (*Entisols*)	Other Entisols (*Orthents*)	Ustic moisture regime (*Ustorthents*)	Lithic contact depth < 50 cm (*Lithic ustorthent*)	Loamy skeletal mixed hyper thermic
P_3 (Valley)	Khatwada	25^{0}34'08" N 75^{0}36'19" E	3-8	Cambic horizon (*Inceptisols*)	Other Ustepts (*Ustepts*)	Ustic moisture regime (*Haplustepts*)	Meets the central concept of great group (*Typic haplustepts*)	Fine loamy mixed hyper thermic
P_4 (Plain-very gently to nearly gently sloping)	Sawangarh	25^{0}38'46" N 75^{0}44'36" E	1-3	Cambic horizon (*Inceptisols*)	Other Ustepts (*Ustepts*)	Ustic moisture regime (*Haplustepts*)	Meet the central concept of great group (*Typic haplustepts*)	Fine loamy mixed calcareous hyper thermic
P_5 (Nearly level plain-I)	Kanwar	25^{0}43'03" N 76^{0}06'56" E	1-3	Cambic horizon (*Inceptisols*)	Other Ustepts (*Ustepts*)	Ustic moisture regime (*Haplustepts*)	Meets the central concept of great group (*Typic haplustepts*)	Fine mixed calcareous hyper thermic
P_6 (Nearly level plain-II)	Raitoda	25^{0}44'11" N 75^{0}59'18" E	1-3	Intersecting slikensides cracks>50 cm deep (*Vertisols*)	Other Usterts (*Usterts*)	Ustic moisture regime (*Haplusterts*)	Meets the central concept of great group (*Typic haplusterts*)	Fine calcareous hyper thermic

*Mixed mineralogy and hyper thermic temperature regime considered for all soils to classify at family level ; [$]Name in parentheses represents respective class

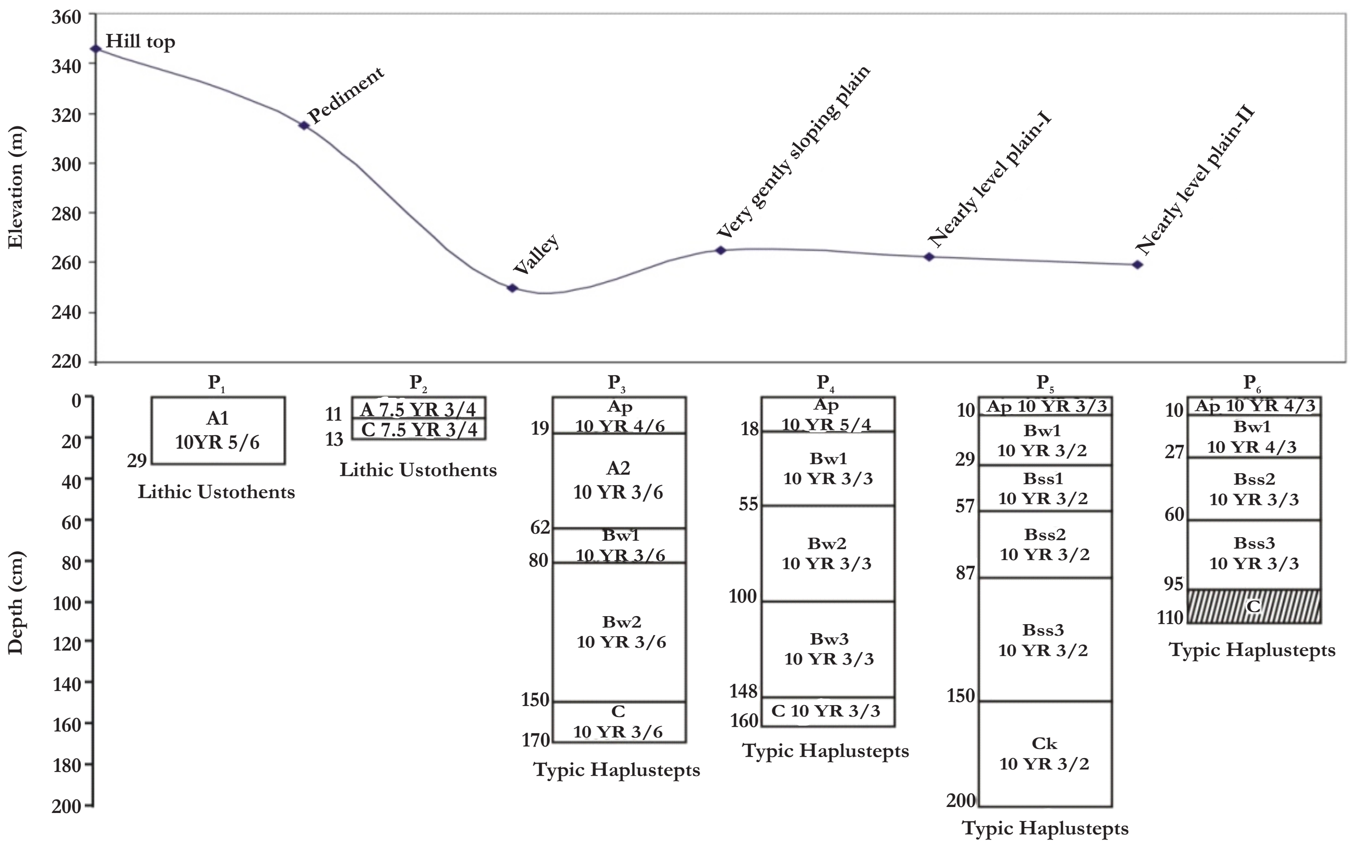

Fig. 2. Soil physiographic relationship in Eastern Rajasthan Upland of Bundi district of Rajasthan

disperse them for particle size analysis by the international pipette method (Piper, 1950). The pH and EC of soils were determined by using 1:2 soil & water suspension and 1:2 soil & water extract using solubridge, respectively (Richards, 1954). Organic Carbon (OC) was determined by Walkley and Black wet digestion method (Jackson, 1958). The cations were displaced and extracted with 1.0 N ammonium acetate. The Ca^{2+} and Mg^{2+} in the extracts were determined by Versenate titration method and the exchangeable Na^{+} and K^{+} by flame photometry. Weighting of the data was employed to remove horizon bias. Weighting was done by multiplying the laboratory value to the thickness of each horizon, summing and dividing by the solum thickness (Ovalles and Collins, 1986). The variation in catenary properties of the soils was analyzed with means and standard deviations from means of weighted data. The influence of topography was quantified by way of simple regression model. The clay content, an index soil property was regressed against the different soil characteristics to gauge the impact of topography on the soil development. Soils were classified as per 'Keys to Soil Taxonomy' (Soil Survey Staff 2010) in Entisols, Inceptisols and Vertisols dominant soil orders based on the physico-chemical and morphological characteristics of soils.

Soil Productivity Assessment

Land evaluation for actual and potential productivity was calculated based on the method described by Riquier *et al.* (1970). Soil productivity (P) was calculated considering nine factors *viz.*, soil moisture content (H), drainage (D), effective depth of soil (P), texture and structure of rooting zone (T), pH in 1:2 soil and water suspension (N), organic matter in surface horizon (O), mineral exchange capacity (A), soluble salt content (S) and nutrient reserve (M). The actual factor-wise scores for different land uses, expressed in percentage were multiplied to derive the final index. Each factor was rated on a scale from 0 to 100 and the resultant index of productivity, also lying between 0 and 100, was set against a scale placing the soil in one or other of five productivity classes. The productivity of soils was worked out as follow:

$$\text{Productivity (P)} = H \times D \times P \times T \times N \times O \times A \times M$$

The potentiality (P') was calculated after a careful consideration of the possible improvement measures in different factors. The productivity (P) and potentiality (P') of ER upland soils were classified under excellent, good, average, poor and extremely poor categories based on productivity index *i.e.* varying from 65-100, 35-64, 20-34, 8-19 and 0-7, respectively. The Coefficient of Improvement (CI) was calculated as follows:

$$\text{Coefficient of Improvement (CI)} = \frac{\text{Potential productivity (P')}}{\text{Actual productivity (P)}}$$

3. RESULTS AND DISCUSSION

Morphological Characteristics

The morphological characteristics of ER upland soils showed considerable variations. Solum thickness varied from 13-200 cm (Table 3). The depth of soils in ER upland was a combined accomplishment of topography, type of basement rock and configuration of the landscape. Soils were very shallow on hill top (P_1) and shallow on pediments (P_2) while moderately deep to very deep on valley (P_3), very gently sloping plain (P_4) and nearly level plain (P_5 and P_6). Gentle to moderate slope, rapid runoff and severe erosion accounted for very shallow to shallow soils on the elevated segment of transect. Soils of elevated topography showed yellowish brown tint which becomes dark brown (10YR 3/3) or very dark grayish brown (10YR 3/2) as topography gets gentler with relatively brighter surface horizons. The dominant hue was 10YR except in two horizons of P_2 (pediments) where it was 7.5YR. The value of the soil color ranged from 3 to 8 and the chroma from 2 to 6. Higher chroma (3-6) was observed in soils of all pedons except P_5. Low chroma (=2) in Kanwar series (P_5) indicates aquic characteristics associated with seasonal reducing conditions. Soils on higher topography position had better drainage condition and exhibit bright color; while soils on lower elevation position had moderate drainage conditions hence exhibit subdued shade (Prasad *et al.,* 1989). Drainage and organic carbon as influenced by topography seemed to be an important factor for color variation. Color variation could also be elaborated as the function of chemical and mineralogical composition, textural make up of soils and moisture regime as conditioned by topographic position (Leelavathi *et al.,* 2009; Kumar and Prasad 2010). The results corroborated with the findings of Raj Kumar *et al.* (2005); Maji *et al.* (2005).

Physical Characteristics

The texture of transect's soil varied from sandy clay loam to clayey (Table 3). High content of coarser fragment was observed in hill (P_1), pediments (P_2) and valley (P_3) soils throughout profile as compared to other land forms. Fine sand constituted the major portion of the total sand. The soils of pediment (P_2), valley (P_3) and very gently sloping plain (P_4) exhibited intermediated trend of per cent sand, silt and clay contribution toward the mechanical composition of these soils. In general, soil texture was coarser on the higher topographic landforms because of removal of finer fractions

Table: 3
Morphological characteristics of genetic horizons on different physiographic units of ER upland transect

Profile	Depth (cm)	Horizon designation	Colour (moist)	Texture	Gravel volume (%)	Structure	Reaction with HCl 0.01 N
Eastern Rajasthan Upland							
Hills (Umar)							
P_1	0-29	Al	10YR 5/6	scl	40-50	sg	e
Pediments (Sela Ka Data)							
P_2	0-11	A1	7.5YR 3/4	scl	10	mc_1sbk	-
	11-13	C	7.5YR 3/4	scl	>80	mc_1sbk	-
Valley (Khatvada)							
P_3	0-19	Ap	10YR 4/6	scl	-	mc_1sbk	-
	19-62	A2	10YR 3/6	scl	-	mc_1sbk	-
	62-80	Bw1	10YR 3/6	scl	-	m_2sbk	-
	80-150	Bw2	10YR 3/6	scl	-	mf_2sbk	-
	150-170	C	10YR 3/6	scl	-	massive	es
Very gently sloping plain (Sawntgarh)							
P_4	0-18	Ap	10YR 5/4	scl	-	mc_1sbk	es
	18-55	Bw1	10YR 3/3	scl	-	mc_1sbk	e
	55-100	Bw2	10YR 3/3	scl	-	mf_2sbk	e
	100-148	Bw3	10YR 3/3	scl	-	f_3sbk	ev
	148 -160	C	10YR 3/3	scl	-	massive	ev
Nearly level plain- I (Kanwar)							
P_5	0-10	AP	10YR 3/3	cl	-	m_2sbk	e
	10-29	Bw1	10YR 3/2	c	-	m_2abk	es
	29-57	Bss1	10YR 3/2	c	-	m_2abk	es
	57-87	Bss2	10YR 3/2	c	-	m_2abk	es
	87-150	Bss3	10YR 3/2	c	-	m_2abk	es
	150-200	Ck	10YR 3/2	Weathered material of schist			es
Nearly level plain- II (Raitoda)							
P_6	0-10	AP	10YR 4/3	c1	-	mc_1sbk	e
	10-27	Bw1	10 YR 4/3	cl	-	m_2sbk	e
	27-60	Bw2	10 YR 3/3	cl	-	m_2sbk	e
	60-95	Bw3	10YR 3/3	cl	-	m_2sbk	es
	95-110	C				massive	ev

of sand, silt and clay under the influence of erosion. The eroded material especially finer fractions got accumulated in the valley or plains which resulted in to the higher load of finer fractions in respective part of transect. In the soils of low laying area (P_3-P_6), the clay/finer fractions increased with depth, reached a maximum and then decreased thereafter indicating fairly well developed soils (Sarkar *et al.,* 2001). The abrupt variations in clay content of some horizons indicate evaluation of particular layer from different lithology. The variation in clay content among the representative profiles was found > 10% (Table 4), suggested heterogeneity of parent material while vertical distribution of clay and silt indicates the monogenic character of each profile. Stable topography, drifting and accumulation of hill wash brought over due to break in slope on valley, very gently sloping plain and nearly level plains (P_3-P_6) brought about the sandy clay loam, sandy loam, clay loam to clay soils texture on the respective topographical position. The maximum amount of clay in second to fifth soil horizons exhibited expressions of textural profile formation (Miller and Turk, 1958). The variation in parent rock, the portions of the landscape and the some from where the matter was carried by erosion agents determines the texture of the soil as a function of topography (Gupta *et al.,* 1999, Sarkar *et al*., 2001; Maji *et al.,* 2005).

Comparatively unstable topography provoked single grain structure on hills. The structure became fine to medium, coarse, weak to moderate sub angular blocky structure in pediments and upper horizon of pedons P_3, P_4 and P_6. The soils of P_5 revealed medium moderate sub angular blocky in upper horizon and medium moderate angular blocky in subsequent horizons. The most dominant structure recorded was sub-angular blocky with weak to moderate strength, indicates that processes of profile development are still in operation (Kumar and Kumaraswamy, 2000). The stability of topography allowed the soil forming factors to put forward their imprints in the soils of nearly level plains. A massive soil structure in lower depth of pedons (P_3, P_4 and P_6) was recorded. The presence of higher

Table: 4
Selected important physical properties of soils on various landforms in ER Upland

Pedons	Horizon designation	Mechanical composition (%)					Bulk Density	Particle Density	Porosity (%)
		Sand			Silt	Clay	(Mg m^{-3})		
		Size in (mm)							
		CS*	FS*	TS*	0.05-0.002	<0.002			
		2.0-0.25	0.25-0.05	0.05-2.0					
Hill (Umar series)									
P1	Al	19.46	29.21	48.67	35.26	16.07	1.44	2.58	44.18
Pediments (Sela ka Data sereies)									
P2	A	17.99	22.62	40.61	37.94	21.45	1.43	2.56	44.14
	C	15.7	20.89	37.59	34.06	28.34	1.59	2.60	40
Valley (Khatwadw sereies)									
P3	Ap	4.98	45.34	50.32	33.07	16.61	1.62	2.58	37.2
	A2	2.55	38.13	40.68	32.83	26.49	1.65	2.65	37.73
	Bw1	2.3	36.17	38.47	33.74	27.79	1.68	2.57	34.63
	Bw2	1.86	45.14	47	32.47	20.53	1.58	2.63	39.92
	C	2.47	51.4	53.87	30.02	16.11	1.64	2.65	38.11
Very gently sloping plain (Sawntgarh series)									
P4	Ap	3.63	33.52	37.15	36.95	25.9	1.48	2.54	41.73
	Bw1	1.81	22.1	23.91	44.13	31.96	1.53	2.50	37.6
	Bw2	1.37	20.65	22.02	38.56	39.42	1.43	2.57	44.35
	Bw3	4.26	10.63	14.89	43.31	41.8	1.48	2.56	42.18
	C	22.94	12.03	34.97	35.12	29.91	1.51	2.49	39.35
Nearly level plain- I (Kanwar series)									
P5	AP	1.37	9.83	11.2	43.85	44.95	1.49	2.53	41.1
	Bw1	1.22	9.16	10.38	43.62	46	1.52	2.54	38.18
	Bss1	0.97	8.43	9.4	41.63	48.97	1.63	2.57	37.15
	Bss2	1.76	6.36	8.12	44.19	47.69	1.59	2.54	37.4
	Bss3	1.13	6.97	8.1	45.43	46.47	1.57	2.56	38.22
	Ck	0.53	8.95	9.48	40.77	49.75	1.62	2.53	35.96
Nearly level plain- II (Raitoda series)									
P6	AP	1.5	16.54	18.04	45.67	36.29	1.47	2.65	44.52
	Bw1	2.03	16.14	18.17	36.6	42.23	1.52	2.53	39.92
	Bw2	2.29	23.26	25.55	28.73	45.72	1.51	2.53	40.31
	Bw3	2.95	14.07	16.52	39.87	43.61	1.56	2.60	40
	C	7.02	12.77	19.79	38.71	41.15	1.59	2.60	38.84

*CS= Coarse sand, FS= Fine sand, and TS= Total sand quantity of coarse fragment and their cementation by $CaCO_3$ might prop up aggregates to coagulate, resulted in to massive structure (Karmakar and Rao, 1999).

The values of bulk density revealed increasing trend with the depth (Table 4) and it ranged from 1.43 to 1.68 Mg m^{-3} with a weighted mean of 1.51 Mg m^{-3} (Table 6). The highest bulk density (1.68 Mg m^{-3}) was observed in Bw_1 horizon of valley (P_3) and lowest (1.44 Mg m^{-3}) was observed in the soils of hill top (P_1). Increased bulk density in the subsurface horizons was observed in all the pedons of transect. The increased bulk density of B horizons in all pedons could be attributed to the densification and accumulation of finer fraction and heavy minerals elluviated from the surface horizon (Nayak *et al.,* 2001; Marathe *et al.,* 2003; Chaudhary *et al.* (2005). Higher bulk density in lower horizons could also be ascribed to the greater compaction coupled with decrease in organic matter down to the profile. The particle density of the soils of ER upland was varied from 2.53 to 2.65 mg m^{-3}. The difference in particle density of different landform in ER upland suggested heterogeneity in profile development (Datta *et al.,* 1990; Singh, 1999). The porosity of various pedons varied from 34.63 to 44.52% (Table 4) with a weighted mean value of 40.90% in soils of ER upland (Table 6). This difference was mainly due to variation in silt and sand fractions and their arrangement.

Chemical Properties

The specificity of relationship between soils and physiography is interpreted with the help of chemical properties. Exchangeable Ca^{2+} was the dominant cation in these soils ranging from 6.24-21.9 C mol (P^+) kg^{-1} followed by exchangeable Mg^{2+} 3.65-12.5 C mol (P^+) kg^{-1}, exchangeable K^+ 0.2- 0.8 C mol (P^+) kg^{-1} and exchangeable Na^+ 0.1-0.6 C mol (P^+) kg^{-1} (Table 5) with a weighted mean value of 14.04, 7.98, 0.61 and 0.45 C mol (P^+) kg^{-1}, respectively (Table 6). The soils of plains (P_4, P_5 and P_6) contained maximum average exchangeable Ca^{2+}, Mg^{2+}, K^+ and Na^+ while the soils of pediments (P_2), valley (P_3) and hill top (P_1) come next with respect to these cations. No specific trend of distribution emerged out with respect to the exchangeable potassium and sodium. Exchangeable Ca^{2+} and Mg^{2+} and their ration increased with depth in plains indicate the movement of calcium downward and accumulation of $CaCO_3$ in subsurface horizons (Walia and Chamuah 1994; Maji *et al.,* 2005).

Cation exchange capacity is a general indicator of soil storage capacity for available and positively charged plant

Table: 5
Salient chemical characteristics of representative profiles of the ER upland transect

Profile	Depth (cm)	Ex-changeable cations (C mol (p^+) kg^{-1})				BS (%)	ESP (%)	CEC C mol (p^+) kg^{-1}	pH (1:2)	EC (dS m^{-1})	OC (g kg^{-1})	$CaCO_3$ (g kg^{-1})
		Ca^{++}	Mg^{++}	Na^+	K^+							
Hills (Umar)												
P_1	0-29	6.96	5.05	0.45	0.74	94.62	3.22	13.95	7.53	0.10	7.90	0.00
Pediments (Sela Ka Data)												
P_2	0-11	10.85	5.43	0.45	0.58	98.35	2.55	17.60	8.04	0.07	4.65	0.00
	11-13	12.28	7.92	0.30	0.79	92.96	1.31	22.90	8.14	0.17	4.07	0.00
Valley (Khatvada)												
P_3	0-19	6.24	3.65	0.12	0.38	91.62	1.05	11.34	7.56	0.07	5.70	0.00
	19-62	12.25	6.12	0.29	0.34	93.73	1.43	20.27	8.05	0.03	2.09	0.00
	62-80	13.97	6.96	0.50	0.43	92.04	2.28	23.75	8.22	0.04	2.47	0.00
	80-150	11.40	5.25	0.42	0.55	95.76	2.28	18.40	8.26	0.05	1.33	0.00
	150-170	11.00	5.23	0.28	0.45	98.03	1.61	17.30	8.76	0.09	1.33	117.60
Very gently sloping plain (Sawntgarh)												
P_4	0-18	12.00	5.50	0.45	0.48	94.85	2.3	19.43	8.33	0.29	7.94	95.50
	18-55	14.00	7.50	0.58	0.51	94.55	2.56	23.89	8.28	0.30	3.10	73.50
	55-100	14.96	11.60	0.40	0.75	89.79	1.44	30.86	8.20	0.28	3.10	66.10
	100-148	16.40	12.50	0.59	0.67	85.34	1.66	35.34	8.87	0.18	2.13	132.30
	148 -160	13.80	9.20	0.39	0.49	96.29	1.57	24.80	8.88	0.14	2.13	139.70
Nearly level plain- I (Kanwar)												
P_5	0-10	19.20	9.80	0.41	0.52	91.50	1.36	32.71	8.58	0.12	4.87	66.10
	10-29	20.80	10.60	0.42	0.46	94.00	1.22	34.34	8.72	0.08	2.92	51.40
	29-57	21.00	11.20	0.59	0.66	89.65	1.76	37.31	8.60	0.08	2.92	73.50
	57-87	21.60	11.80	0.68	0.73	94.36	1.95	36.89	8.56	0.07	1.94	29.40
	87-150	21.90	11.60	0.49	0.59	97.24	1.41	35.56	8.56	0.09	1.36	73.50
	150-200	21.81	10.90	0.38	0.43	84.30	2.24	39.76	8.67	0.09	1.36	176.40
Nearly level plain- II (Raitoda)												
P_6	0-10	15.78	9.10	0.45	0.23	95.76	1.68	26.69	8.11	0.21	2.70	102.10
	10-27	18.10	10.23	0.52	0.61	95.68	1.76	30.79	8.15	0.13	2.70	124.00
	27-60	19.28	10.78	0.42	0.85	94.94	1.34	33.00	8.33	0.08	2.31	102.10
	60-95	19.37	10.33	0.55	0.68	94.24	1.77	32.82	8.34	0.11	2.31	109.40
	95-110	19.10	8.90	0.38	0.57	95.60	1.31	30.28	8.26	0.09	2.31	226.00

Table: 6
The weighted mean and standard deviation of soil properties averaged across horizons in Eastern Rajasthan upland

Pedons	Sand (0.05-2.00)	Silt (0.05-.002)	Clay (<0.002)	BD ($Mg\ m^{-3}$)	Porosity (%)	Exchangeable cations ($C\ mol\ (p^+)\ kg^{-1}$)			
	(Size in mm)					Ca^{++}	Mg^{++}	Na^+	K^+
	(0.05-2.0)	(0.05-.002)	(<0.002)						
P_1 (n=3)	48.67	35.26	16.07	1.44	44.18	6.96	5.05	0.45	0.74
P_2 (n=6)	40.14±2.14	37.32±2.74	22.47±4.87	1.45±0.11	43.5±2.93	11.07±1.01	5.81±1.76	0.42±0.11	0.61±0.15
P_3 (n=15)	45.3±6.45	32.47±1.42	21.86±5.44	1.61±0.04	38.28±1.91	11.26±2.88	5.47±1.23	0.34±0.15	0.45±0.08
P_4 (n=15)	23.26±9.31	41.11±3.95	36.17±6.64	1.47±0.04	41.49±2.62	14.75±1.62	10.05±2.88	0.5±0.10	0.62±0.12
P_5 (n=18)	9.00±1.23	43.29±1.73	47.76±1.84	1.58±0.06	37.52±1.73	21.46±1.01	11.21±0.73	0.49±0.12	0.56±0.12
P_6 (n=15)	20.09±3.51	36.15±6.14	43.21±3.52	1.52±0.05	40.48±2.20	18.75±1.51	10.26±0.82	0.48±0.07	0.67±0.23
AM[c] of WMa	31.08	37.60	31.26	1.51	40.91	14.04	7.98	0.45	0.61
AM of SD[b]	11.89	8.54	6.40		0.29	9.26	2.50	2.08	0.170.24

Pedons	BS (%)	ESP (%)	CEC [$C\ mol\ (p^+)\ kg^{-1}$]	pH (1:2)	EC (dSm^{-1})	OC ($g\ kg^{-1}$)
P_1 (n=3)	94.62	3.22	13.95	7.53	0.10	7.9
P_2 (n=6)	97.52±3.81	2.35±0.88	18.4±3.75	8.05±0.07	0.08±0.07	4.15±0.41
P_3 (n=15)	94.66±2.68	1.85±0.54	18.52±4.56	8.18±0.43	0.05±0.02	2.13±1.81
P_4 (n=15)	90.61±4.53	1.87±0.49	28.85±6.25	8.48±0.33	0.24±0.07	3.28±2.43
P_5 (n=18)	91.91±4.52	1.73±0.39	36.79±2.46	8.6±0.07	0.08±0.02	1.98±1.33
P_6 (n=15)	94.93±0.65	1.59±0.23	31.79±2.55	8.27±0.10	0.11±0.05	2.41±0.21
AM[c] of WM[a]	94.04	2.10	24.72	8.19	0.11	3.64
AM of SD[b]	18.47	0.96	5.59	1.42	0.06	2.35

[a]= Weighted Mean, [b]= Standard Deviation, [c]= Arithmetic Mean

nutrients and dominant minerals present in soils. The data on cation saturation (Fig. 3) showed that major portion of the exchange sites was saturated with exchangeable Ca^{2+} and Mg^{2+} ranging from 53 to 64% and 32 to 38%, respectively, throughout the whole profile of all pedons. This was followed by exchangeable K^+ and Na^+ ranging from 2 to 6% and 1 to 3%, respectively. The CEC of the soils varied from 11.34 to 39.76 C mol (p^+) kg^{-1} with a mean value of 24.72 C mol (p^+) kg^{-1}(Table 5, Table 6 and Fig. 4). The maximum value of CEC observed in soils of P_5 [36.79 C mol (p^+) kg^{-1}] and lowest value [13.95 C mol (p^+) kg^{-1}] in hill top pedon and in pediment [18.40 C mol (p^+) kg^{-1}]. The increasing pattern of exchangeable cations with depth is probably due to leaching of these cations from surface layers and subsequent absorption in subsurface horizons. The base saturation ranged from 84.30 to 98.35% with a mean value of 94.04% in soils of ER upland transect (Table 5 and Table 6). The higher base saturation in the soils of the study area is probably because of the basic nature of the parent materials and semi arid climatic conditions which allows bases to accumulate in soil matrix.

Land use changes have a great influence in many soil quality attributes mostly through its effect on soil organic matter. The organic carbon content of the soil ranged from 2.7 to 7.9 g kg^{-1} in the surface and 1.3 to 3.1 g kg^{-1} in the subsurface horizons (Table 5). The soil organic matter content decreased regularly with depth in all soils. The low OC content can be attributed to the prevailing climatic condition and higher temperature in region which enhance the rate of mineralization (Sharma *et al.*, 1999; Walia and Rao, 1996). The silt and clay content collectively accounts for 24.1% variations in OC content of the soils (Eq. 1). The continuous cropping in both the season on the stable landscape might be the reason of decreasing organic carbon content topographically.

$$OC\ (Y) = 2.643 + 0.102\ silt - 0.097\ clay \quad R^2 = 0.241 \quad ...(1)$$

The pH of the soil ranged from 7.53 to 8.88 with a mean value of 8.19, indicates slightly alkaline to strongly alkaline nature of soils (Table 5 and Table 6). The soil pH in most cases was increased with depth in all profiles. This indicates the movement of soluble salts and increased $CaCO_3$ content in subsurface horizons. Saucer shaped topography of plains provoked base accumulative environment. The higher pH values in soils of lower slopes and its increased value with soil depth could be attributed to the deposition of alleviated bases from surrounding upper slopes (Brown and Olsen, 1949; Deshmukh and Bapat, 1993; Chamuah *et al.*, 1996; Sarkar *et al.,* 2001). The clay governs 29.5% variations in soil reaction which indicates a positive impact of topography on pH (Fig. 5). The Electrical Conductivity (EC) of the soil was low (0.03-0.30 dSm^{-1}) indicating no salinity problem in these soils. Even though soluble salt content was low, a general trend of increment in soluble salts in high $CaCO_3$ layers indicates that the movement of soluble salts had a bearing on the $CaCO_3$ content in the profiles (Wilding and Tessier, 1988; Gaikwad *et al.,* 1974).

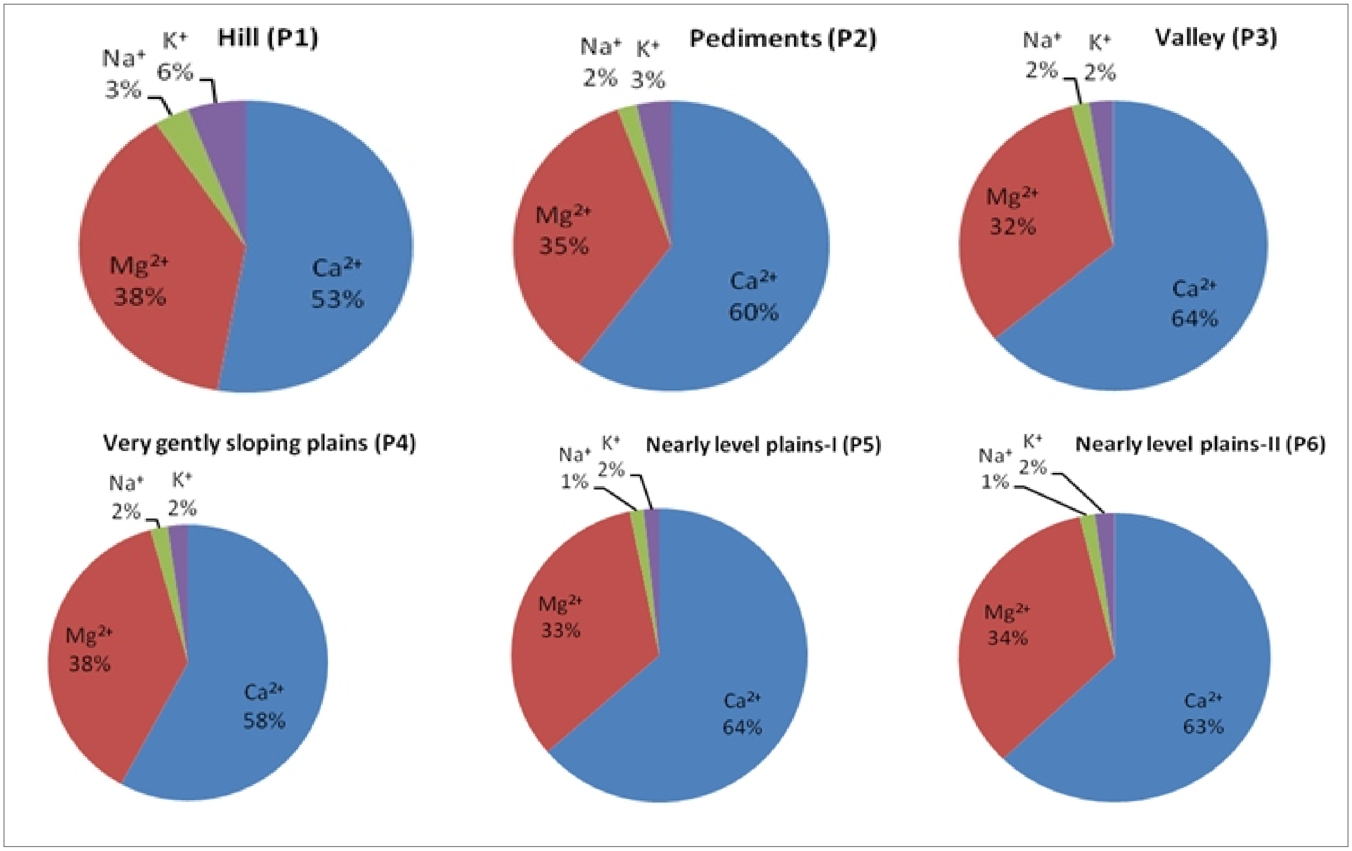

Fig. 3. Cations saturation on soils of different landform units in ER upland

In general, free carbonates owes their origin from parent material as well as are products of weathering. The depth of carbonate leaching is a reliable index of soil weathering and soil development. A specific regular trend of $CaCO_3$ distribution was observed with respect to the topography (hill to plain) in the soils of ER upland. Shallowness of profile and removal of $CaCO_3$ from place of origin was resulted into complete absence of $CaCO_3$ in hill and pediment soils. In the soils of valley (P_3), $CaCO_3$ deposition was recorded in lower most horizons which might be due to downward movement of calcium ions and subsequent precipitation as carbonates in lower layers at higher pH level (West *et al.*, 1988). In surface soils the $CaCO_3$ was found in powdered form while in lower layers it was in the form of nodules plus powder. An abrupt increase in the lower horizons of plains (P_4-P_6) was recorded. The unusual high $CaCO_3$ content in these pedons probably due to the influence of local ephemeral stream deposition. Another possible reason for this might be precipitation of $CaCO_3$ in alkaline range of pH in soil system (Singh *et al.* 1999; Maji *et al.,* 2005; Kumar and Prasad, 2010). The ESP of the soils throughout transect was found within safe limit for most of the crops of the region.

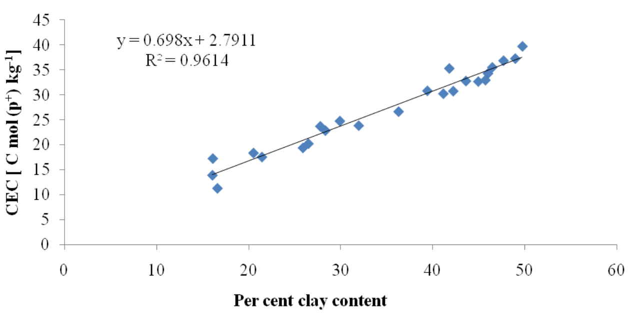

Fig. 4. Relationship of clay with CEC in Eastern Rajasthan Upland

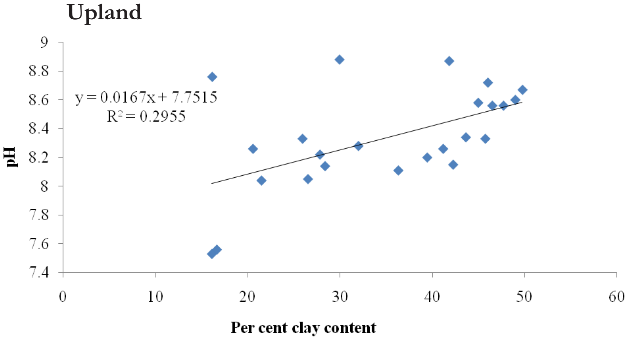

Fig. 5. Relationship of clay with pH in Eastern Rajasthan Upland soils

Soil Classification

The key diagnostic criterion used for soils classification at the different categorical levels and classification of soils is elucidated in the Table 2. The soils of pedon P_3, P_4 and P_5

had cambic endopedon. The soils of pedons P_6 had slickensides within 100 cm of the mineral soil surface while the soils of P_1 and P_2 were characterized by the presence of lithic contacts within 50 cm from the surface. The soils of ER upland transect remains dry all over the moisture control section for > 90 days during the year and qualify for ustic soil moisture regime. The soil temperature was more than 20°C within the control section and difference between MWST and MSST was more than 5°C so, soils qualified for hyperthermic soil temperature regime. Based on these diagnostic features, soils of pedon P_1 and P_2 were classified in Entisols soil order, while the soils of pedon $P_{3,}$ P_4 and P_5 were put under Inceptisols soil order. The soils of pedon P_6 were classified in Vertisol soil order. The soil orders are further taken down to the suborder level. The soils of P_1 and P_2 were placed in orthents suborder. The soils of Inceptisols and Vertisol soil order were classified as a member of ustepts and usterts suborder, respectively. On the basis of particle size, temperature regime and mixed mineralogy, soils were further classified to soil family level. The soils of pedon P_1 and P_2 were classified as a member of loamy skeletal mixed hyper thermic family under Lithic Ustorthents subgroup. The soils of Pedon P_3 had classified as a member of fine loamy hyper thermic family of Typic Haplustepts while the soils of Pedon P_4 and P_5 classified as a member of fine loamy calcareous hyper thermic family of Typic Haplustepts. Soils of Pedon P_6 classified as a fine mixed calcareous hyperthermic family of Typic Haplusterts.

Productivity Potentiality Evaluation

The productivity is a relative term and employed in the sense of soils' capability to produce a certain amount of crop per hectare per annum and is expressed as a percentage of the optimum yield per hectare of that same crop grown on the best soil. Potentiality is that productivity of a soil, when all possible improvements have been made, even the most difficult and costly. It is thus the future productivity of that soil taking into account physical and chemical characteristics as modified by conservation practices or improvements and also those characteristics which are not modifiable by present day technology (Riquier *et al.,* 1970). The productivity index (P), potentiality index (P') and CI of the soils for different land uses are presented in Table 7. The productivity of the soils of hill (P_1) and pediments (P_2) was extremely poor for crop (1.57%), pasture (5.89%) and tree (0.12%). Although productivity of these soils for pasture production can be upgraded up to poor category level (8.75%) by adopting some soil and moisture conservation practices with nutrient management. The productivity for crop production was average in P_3 (29.43%), P_4 (31.07%), P_5 (27.62%) and P_6 (31.07%). With adoption of good agronomic practices like moisture conservation, addition of organic matter for improving physico-chemical properties like structure, BD, tillth pH, EC *etc.* with nutrient management, the productivity class of these soils can be upgraded to good (50.40 to 53.87%). For pastures, the productivity (P) was 17.66, 18.64, 16.57 and to 18.64% with respect to P_3, P_4, P_5 and P_6 landforms, respectively. Correction in soil pH by application of gypsum or other available soil amendments with adoption of agronomic practices like moisture conservation and nutrient management with irrigation facility, the productivity of these soils can be improved to good in P_3 (46.17%), P_4 (46.17%), P_5 (43.20%) and to P_6 (46.17%). For commercial crops (forestry and non-forestry), the productivity (P) of the soils was extremely poor. The potentiality (P') of these soils can be improved to average by adopting some excellent package of practices with intensive care. The potential of ER upland soils for crop, pasture and commercial crops production can be improved by adopting management practices as indicated by coefficient of improvement (varied from 0.93 to 5.23%). The results indicate that the soils on Sawantgarh series (P_4) and Raitoda series (P_6) had the highest potentiality for crop and pasture production while the soils on plains (P_4-P_6) can considerably be improved for commercial trees.

4. CONCLUSIONS

Characterization of land resources revealed that, the soils are shallow to very shallow in upper and middle reach and deep to very deep in lower reach of the transect. The soils of hills and pediments are erosional surfaces and soils of lower reach are depositional surfaces with deep shrink-swell soils. Drainage and organic carbon as influenced by topography plays an important role in color variation. The cultivated soils, in general low in organic carbon. The most dominant structure in ER upland is sub-angular blocky with weak to moderate strength, indicates a process of profile development is still in operation. Based on the physico-chemical and morphological characteristics, soils of transect are classified under Entisols, Inceptisols and Vertisols orders. The soils on different landforms were at varying degree of pedogenic development and have different productivity and potentiality for specified land uses. The productivity of the soils of hills and pediments is extremely poor or nil. The productivity of valley and plain transect's soils is average. The potentiality of ER upland soils for crop, pasture and commercial crops production can be improved by adopting management practices as indicated by coefficient of improvement (varied from 0.93 to 5.23%). The soil resource data generated in present investigation could be utilized for soil resource management in ER upland. The generated data help in to determine the yield controlling factors across the upland and their spatial distribution. The present study also provides a fair opportunity of matching between input resources and yield determining factors so as to maximize plant performance and minimize off site environmental

Table: 7
Assigned scores of soil characteristics for specific land use and productivity index (P), potentiality index (P') and CI of soils of ER upland

Pedon	SLU	H	D	P	T	N	O	A	M	S	P	P'	CI
P_1	C	40	90	20	30	100	85	90	95	100	1.57	3.89	2.48
		(40)	(90)	(20)	(60)	(100)	(100)	(90)	(100)	(100)			
	P	30	90	60	50	100	85	90	95	100	5.89	8.75	1.49
		(30)	(90)	(60)	(60)	(100)	(100)	(90)	(100)	(100)			
	T	10	40	5	80	100	85	90	95	100	0.12	0.11	0.93
		(10)	(40)	(5)	(60)	(100)	(100)	(90)	(100)	(100)			
P_2	C	40	90	20	30	100	85	90	95	100	1.57	3.89	2.48
		(40)	(90)	(20)	(60)	(100)	(100)	(90)	(100)	(100)			
	P	30	90	60	50	100	85	90	95	100	5.89	8.75	1.49
		(30)	(90)	(60)	(60)	(100)	(100)	(90)	(100)	(100)			
	T	10	40	5	80	100	85	90	95	100	0.12	0.11	0.93
		(10)	(40)	(5)	(60)	(100)	(100)	(90)	(100)	(100)			
P_3	C	50	90	100	90	100	85	90	95	100	29.43	53.87	1.83
		(70)	(90)	(100)	(90)	(100)	(100)	(95)	(100)	(100)			
	P	30	90	100	90	100	85	90	95	100	17.66	46.17	2.61
		(60)	(90)	(100)	(90)	(100)	(100)	(95)	(100)	(100)			
	T	10	40	100	90	100	85	90	95	100	2.62	13.68	5.23
		(40)	(40)	(100)	(90)	(100)	(100)	(95)	(100)	(100)			
P_4	C	50	90	100	90	100	85	95	95	100	31.07	53.87	1.73
		(70)	(90)	(100)	(90)	(100)	(100)	(95)	(100)	(100)			
	P	30	90	100	90	100	85	95	95	100	18.64	46.17	2.48
		(60)	(90)	(100)	(90)	(100)	(100)	(95)	(100)	(100)			
	T	10	40	100	90	100	85	95	95	100	2.76	13.68	4.95
		(40)	(40)	(100)	(90)	(100)	(100)	(95)	(100)	(100)			
P_5	C	50	90	100	80	100	85	95	95	100	27.62	50.40	1.82
		(70)	(90)	(100)	(80)	(100)	(100)	(100)	(100)	(100)			
	P	30	90	100	80	100	85	95	95	100	16.57	43.20	2.61
		(60)	(90)	(100)	(80)	(100)	(100)	(100)	(100)	(100)			
	T	10	40	100	80	100	85	95	95	100	2.45	12.80	5.21
		40	(40)	(100)	(80)	(100)	(100)	(100)	(100)	(100)			
P_6	C	50	90	100	90	100	85	95	95	100	31.07	53.87	1.73
		(70)	(90)	(100)	(90)	(100)	(100)	(95)	(100)	(100)			
	P	30	90	100	90	100	85	95	95	100	18.64	46.17	2.48
		(60)	(90)	(100)	(90)	(100)	(100)	(95)	(100)	(100)			
	T	10	40	80	90	100	85	95	95	100	2.21	10.92	4.95
		(40)	(40)	(80)	(90)	(100)	(100)	(95)	(100)	(100)			

SLU= Specified land use, C= Crop, P= Pasture, T= Trees, Figures in parenthesis represents potentiality rating scores

effects. Next to this study, more research should be devoted to these important topics, particularly for validation of usefulness of land productivity index for decision making and implantation. The similar research should also be conducted for different soil types to highlight productivity potential of soils of various landforms.

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