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Soil properties and erodibility status in relation to land uses in a Giri river micro-watershed in Solan district of Himachal Pradesh

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ABSTRACT

Investigations were undertaken during 2011 for computing and comparing soil hydro-physical and chemical properties and erodibility status under different land uses (agricultural, orchard, scrub, agri-silvi-horti lands) in micro-watershed of Giri river catchment (Ga3a) in Solan district of Himachal Pradesh. Results revealed that soils of micro-watershed under all land uses were neutral in reaction, lighter in texture having gravely silt loam textural class. Among land uses, orchard soils had lowest bulk density and better aggregate stability. Water retention under different land uses followed the order: Orchard > agri-silvi-horti > agriculture > scrub lands. Soils were low in available N, very high in P and low to medium in K status. As per the erodibility indices *viz.,* Dispersion ratio (DR), Erosion ratio (ER), Erodibility index (EI), soils under all land uses were found erodible in nature but the orchard and agri-silvi-horti lands were less erodible than soils under agricultural and scrub lands and followed the order for the susceptibility to erosion: Scrubs > agriculture > Agri-silvi-horti > orchard land. There is a need to adopt suitable soil and water conservation measures in agricultural and orchard lands to sustain their health for sustaining the crop production by checking soil erodibility.

1. INTRODUCTION

Himachal Pradesh is a hilly state endowed with varied climate and physiography having mild to steep slopes coupled with fragile geology and skewed rainfall pattern. Such physiographic conditions accelerate runoff and make the lands susceptible to severe water erosion. Majority of the lands/watersheds in the state are subjected to water erosion of varying degrees. The problem of excessive runoff and soil erosion is more pronounced in sub-montane zone of lower Shiwaliks comprising the catchments of river Giri, Swan, Chakki, Ghaggar and Markana. The soil erosion map of Himachal Pradesh have showed wide variations in erosion rates varying from as low as 0.08 t $ha^{-1}yr^{-1}$ to as high as 683.10 t $ha^{-1}yr^{-1}$ (Yadav and Sidhu, 2010).

Of all the measurable properties of soils, hydro-physical characteristics and erodibility indices have probably greater utilitarian value. Better utilization of rainfall, irrigation facilities and effective control of soil erosion and runoff depend largely on these soils parameters. Soil texture, organic carbon and MWD to large extent determine the water retention and release and infiltration rate in soil (Sharma *et al*., 1987). Furthermore, for maintaining ecological balance and to develop management strategies, information about various hydro-physical characteristics and nutrient availability is essential. These characteristics have direct relationship with soil health and quality and their knowledge is essential for scheduling agricultural operations, management of soil resources for maintaining better soil environment and for sustainable crop production. Therefore, a study has been conducted in Ga3a micro-watershed of Giri river catchment in Solan district of Himachal Pradesh to evaluate the effect of various land use systems on soil erodibility and related properties.

2. MATERIALS AND METHODS

Location and Climate

The Ga3a micro-watershed is one of the 136 micro-watersheds of Giri river catchment, located in Solan district of Himachal Pradesh and lies between $30^{0}50'$ to $30^{0}53'$ N latitudes $77^{0}08'$ to $77^{0}15'$ E longitudes. It covers Total Geographical Area (TGA) of 2,018 ha with altitude varying from 900 m to 2040 m above msl. This micro-watershed lies in the north-eastern part of Solan forest division. Giri river is one of the tributaries to Yamuna river and bounded by Himalayan mountain in north, Shiwalik ranges in south and lower Himalayas in southwest.

Physiography and Soil

The geology of the micro-watershed reveals Eocene rocks referred to as Subathu formations. Common rocks in the area are slates, phyllites, mica schist, sandstone, limestone, and quartzite. Soils on the upper reaches of the micro-watershed are formed under coniferous vegetation which are rich in organic matter. In lower areas of micro-watershed, soils are sandy loam with loose boulder and moderate water retaining capacity.

Land Use Classes

The Ga3a micro-watershed encompasses many land uses and dominant ones are forest, agriculture (mostly cereals), orchards, cultivated (mostly vegetable crops), agri-silvi-culture, agri-silvi-horti, grass lands and scrub lands. Four land uses *viz.,* orchard, agriculture, agri-silvi-horti and scrub lands were taken into consideration in the present study and the remaining four covered under other study. The selected land uses are briefly described as under:

Agricultural lands

Occupy approximately 7-8% of the TGA of the micro-watershed with 0-5% slope. Generally 2-3 agricultural crops are grown in a year following traditional cultivation practices. Dominant crops grown are wheat, maize, pulses, *etc.* Besides these, some area is under vegetables *viz.,* pea, tomato, cabbage, cauliflower, capsicum, *etc.* Important natural vegetation occurring on the bunds of fields consisted of *Grewia optiva, Morus alba, Bauhinia variegata, Celtis australis, Bombax ceiba, etc.*

Orchard lands

Occupy nearly 2-4% of the TGA of the micro-watershed having 0-10% slope. Well established orchards of peach, plum, apricot, kiwi, *etc.* are equipped with drip irrigation system and basins mulched with grass or polythene sheet. The area outside the basin was infested with weeds *viz., Phalarus minor, Trifolium alexandrinum, Cannabis sativa* and *Sorghum halepense*. Besides orchards, dominant natural vegetation under this land use consisted of *Albizia chinensis, Toona ciliata, Populus deltoides, G. optiva, etc.*

Scrub lands

Occupy nearly 30% of the TGA of the micro-watershed and general slope of the land is 5-20% and about 30-50% area has bushy vegetation. Dominant natural vegetation under this land use consisted of *Acacia nilotica, Dodonaea viscosa* and *Saccharum munja, G. optiva, Murraya koenigii, M. alba, C. australis, etc.* with some other grasses constituting the lower most strata. Trees in the scrub lands are bushy in appearance indicating stunted growth.

Agri-silvi-horti lands

Occupy very less area *i.e.* about 2% of TGA of the micro-watershed and general slope of the land is 3-15%. This land use comprised scattered fields of agricultural crops (Maize, wheat) floricultural crops, agro-forestry and fruit trees on the field bunds. Commonly occurring fodder tree species in this land use are of *G. optiva*, *M. alba*, *B.variegata*, *C. australis, etc.* and some fruit trees *viz.,* peach, plum, apricot, pear, darru (*Punica granatum*), *etc.*

Soil Sampling

On the basis of detailed survey and area under different land use classes, random sampling technique was followed for the selection of sampling sites. Accordingly, 3 representative soil samples from two depths (0.0-0.15 and 0.15-0.30 m) from each of the above described land uses were collected thus making total number of samples 24. Each sample was air dried and divided into two equal parts. One part was processed *i.e.* properly ground in pestle and mortar and passed through 2 mm sieve to analyze the soils for physico-chemical and hydraulic properties. Remaining part was kept unsieved and unprocessed for the determination of aggregate size distribution.

Soil Analyses

Infiltration characteristics

Infiltration studies were carried out under each land use by using double ring metallic infiltrometer. Both infiltration rate (cm hr^{-1}) and cumulative infiltration (cm) were plotted against time for each replicate separately. Smooth curves were drawn through the data obtained from the replicates. The averaged out curves were plotted to represent the average infiltration rate and cumulative infiltration under each land use.

Physical and chemical properties

Particle size analysis was carried out by the International pipette method. Bulk density of soil determined in the field by core method and particle density of disturbed soils was determined in the laboratory by standard pycnometer method. Water Stable Aggregate (WSA) size distribution was determined following the standard wet sieving method outlined by Yoder (1936). Mean Weight Diameter (MWD) was calculated according to the formula of Yonker and Mc Guinness (1957). Soil chemical properties *viz.,* pH, organic carbon, available N, P and K were determined following standard procedures (Jackson, 1973).

Hydraulic properties

Moisture retention of disturbed soil samples was determined at 10, 33, 50, 100, 300, 500, 1000 and 1500 kPa suctions by using pressure plate apparatus (Richards, 1947). Moisture retention between 33 and 1500 kPa suction was computed to calculate available water contents. Saturated hydraulic conductivity (K_s) determined following constant head method and Maximum Water Holding Capacity (MWHC) was determined by K.R. box method (Piper, 1966).

Erodibility indices

Dispersion Ratio (DR) and Erosion Ratio (ER) were computed as per Middleton *et al.* (1930) and erosion index (EI) by Sahi *et al*. (1977). The threshold limits of 15, 10 and 2.8 were used for DR, ER and EI, respectively. Soils having values greater that these limits for a respective index were categorized as erodible in nature.

3. RESULTS AND DISCUSSION

Physical Properties of Soils under Different Land Uses

Mechanical analysis of the soils revealed that sand constituted a major fraction and its contents ranged from 44.57-53.89% under different land uses having gravely silty loam texture (Table 1). Among the land uses, the surface layer of orchard lands had highest clay contents (21.34%). However, the clay contents in the sub-surface layer were found to be highest in agricultural land followed by orchard lands. Least clay contents (17.67 and 21.20%) were recorded in both the soils layers of scrub lands. The soil texture was lighter under all the land uses as sand constituted the dominant fraction. This property is largely related to parent material and soil of the study area are mostly formed from soft sand stone, shales, poorly sorted conglomerates and alluvium/colluviums derived materials having poor aggregating qualities. Sidhu *et al*. (2000) also recorded lighter texture in soils of northwestern Shiwaliks.

Soil bulk density varied from 1.26-1.58 Mg m^{-3} under different land uses and increased with depth (Table 2). However, it was highest and almost equal under scrub lands (1.58 and 1.57 Mg m^{-3}) in both the soil layers and lowest in orchard lands (1.26 and 1.29 Mg m^{-3}). Comparatively higher bulk density for soils of scrub lands may be attributed to lower clay and organic carbon contents. Like bulk density, particle density was higher in sub-surface layer compared to the surface layer in all land uses which could be ascribed to comparatively higher organic matter contents in the surface layers under all land uses.

Both WSA (>0.25 mm) and MWD were highest in orchard lands *i.e.* 58.04 and 57.31%; 4.25 and 4.10 mm in 0.0-0.15 and 0.15-0.30 m soil depths, respectively followed by agri-silvi-horti lands (Table 2). The lowest WSA (>0.25 mm) were recorded in agricultural land use (37.28 and 36.79%) both in surface and subsurface depths, respectively. Comparatively higher MWD under orchard lands indicates that these soils are less erodible than other land uses. Better aggregation leading to higher MWD and stability of aggregates in orchard lands was probably due to accumulation of high organic matter and clay. Both MWD and WSA (>0.25 mm) were found to have positive and significant correlation between themselves in all the land uses in the micro-watershed except in scrub lands. However, MWD and WSA (< 0.25 mm in diameter) showed a negative relationship with each other in all the land uses except for soils under scrub lands ($r = 0.75$).

Hydraulic Properties of Soils under Different Land Uses

Water retained by soils at different suctions under different land uses was quite good and differed widely in their capacity and availability (Fig. 1 and Fig. 2). Highest moisture retention at 33 and 1500 kPa suctions was observed in orchards lands being 22.74 and 23.1%; 6.78 and 5.91% in 0.0-0.15 and 0.15-0.30 m soil layers, respectively. This could be ascribed to the higher organic carbon due to regular addition of farm yard manure and less disturbance in orchard lands compared to agricultural lands, coupled with higher percentage of clay as increased organic matter encourages soil aggregation, which in turn might have increased the water retention at 33 and 1500 kPa. Increase in soil water storage under orchard land use could also be attributed to reduced evaporation, greater infiltration, and soil protection from raindrop impact. Lowest percentage of moisture retention at 33 and 1500 kPa suctions was observed in scrub lands in both the soil depths (17.06 and 14.64%; 3.86 and 3.38%) which may be attributed to their coarse texture *i.e.* higher sand contents which causes

Table: 1
Mechanical composition and texture of soils under different land uses

Land use	Depth (m)	Gravel (%)	Coarse sand (%)	Fine sand (%)	Total Sand (%)	Silt (%)	Clay (%)	Textural class
Orchard	0.0-0.15	34.16	18.56	27.14	45.70	33.96	21.34	gsil
	0.15-0.30	36.94	17.70	26.87	44.57	31.73	23.70	gsil
Agri-silvi-horti	0.0-0.15	28.70	22.98	25.94	48.92	29.72	20.36	gsil
	0.15-0.30	32.50	18.50	27.60	46.10	32.50	21.40	gsil
Agriculture	0.0-0.15	27.25	25.35	25.35	53.11	29.22	19.41	gsil
	0.15-0.30	31.27	19.82	30.80	50.62	26.57	23.81	gsil
Scrub	0.0-0.15	40.10	31.40	22.49	53.89	26.69	17.67	gsil
	0.15-0.30	43.80	32.00	18.60	50.70	28.20	21.20	gsil

Table: 2
Physical properties of soils under different land uses

Land uses	BD ($Mg\ m^{-3}$)		PD ($Mg\ m^{-3}$)		MWD (mm)		WSA (> 0.25 mm %)		WSA (< 0.25 mm %)		AW (w/w, %)		MWHC (%)		K_s x 10^{-5} (ms^{-1})	
	Soil depths (m)															
	0.0-0.15	0.15-0.30	0.0-0.15	0.15-0.30	0.0-0.15	0.15-0.30	0.0-0.15	0.15-0.30	0.0-0.15	0.15-0.30	0.0-0.15	0.15-0.30	0.0-0.15	0.15-0.30	0.0-0.15	0.15-0.30
Orchard	1.26	1.29	2.43	2.47	4.25	4.10	58.04	57.31	41.96	42.69	15.96	17.19	40.70	37.92	1.58	1.46
Agri-silvi-horti	1.26	1.33	2.57	2.58	3.71	3.70	56.50	55.02	43.50	44.98	15.44	15.11	40.32	37.21	1.53	1.43
Agri.	1.48	1.49	2.61	2.63	3.64	3.55	37.28	36.79	62.72	63.21	14.69	14.97	41.25	38.82	1.48	1.42
Scrub	1.58	1.57	2.73	2.77	2.50	2.49	42.22	45.13	57.78	54.87	13.20	11.26	37.19	34.92	1.30	0.91
Mean	1.39	1.41	2.58	2.61	3.52	3.46	48.50	48.56	51.49	51.47	14.82	14.63	39.86	37.21	1.47	1.30
Lsd	0.24	0.18	NS	NS	NS	NS	3.42	6.31	NS	NS	1.91	NS	1.85	4.13	0.44	0.10

Significant at 5% level

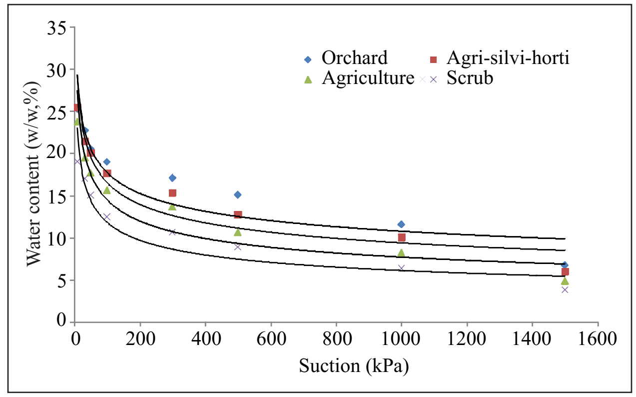

Fig. 1. Soil moisture retention under different land uses in 0.0-0.15 m soil layer

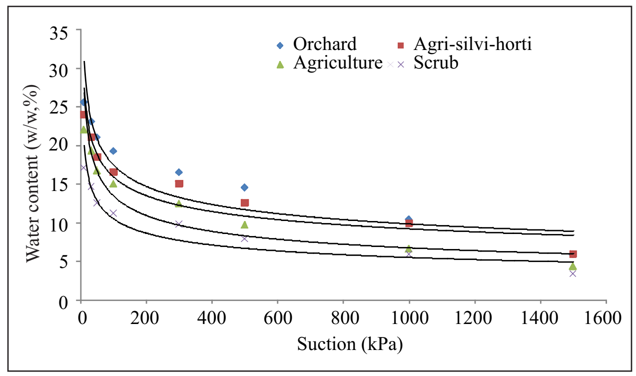

Fig. 2. Soil moisture retention under different land uses in 0.15-0.30 m soil layer

the soil to drain easily and quickly after rain which consequently leads to lower moisture and nutrient retention capacity (Table 2).

Among land uses, available water (AW) was found to be highest in orchard soils (15.96 and 17.19%) followed by agri-silvi-horti (15.44 and 15.11%), agricultural (14.69 and 14.97%) and lowest in scrub lands (13.20 and 11.26%) (Table 2). Higher organic carbon contents coupled with higher clay contents in orchard lands might have enhanced the AW. However, low percentage of AW in both the soil layers of scrub lands may be ascribed to higher percentage of sand and low clay and organic carbon contents. Likewise, MWHC was also highest in orchard lands (40.70 and 38.92%) in both the two soil layers that can be explained by the occurrence of higher amount of organic carbon in the surface than sub-surface soils, which might have helped to form aggregates and retain more water.

Saturated hydraulic conductivity (K_s) among different land uses was found to be highest in orchard lands (1.58 and $1.46 \times 10^{-5} ms^{-1}$) and lowest in scrub lands (1.30 and $0.91 \times 10^{-5} ms^{-1}$) both in 0.0-0.15 and 0.15-0.30 m soil depths (Table 2). According to the ratings of K_s, all land uses were placed under moderately slow to moderately rapid categories. Highest K_s in orchard land may be ascribed to its lower bulk density as compared to scrub land use which has highest bulk density among different land uses.

Both steady state and cumulative infiltration varied widely among different land uses and were comparatively higher in orchard lands compared to agri-silvi-horti, agricultural and scrub lands (Fig. 3). The soil profiles under orchard land use had greater percentage of water stable aggregates and MWD in the surface layers which keeps the porosity imtact thus favoring higher infiltration. Lower infiltration rate in agricultural land could be ascribed to the low vegetative cover and poor soil aggregation due to continuous ploughing.

Chemical Properties of Soils under Different Land Uses

Soils of the micro-watershed were neutral in reaction with pH ranging from 6.65 to 7.41 under different land uses (Table 3). However, the lowest pH *i.e.* 6.65 was recorded in orchard soil in 0.0-0.15 m depth and highest *i.e.* 7.21 in scrub lands and there was no wider variations in pH among different land uses.

Organic carbon contents were found to be higher in surface layers under all land uses and decreased with depth which could be due to accumulation of organic matter through leaf litter in the upper horizons (Table 3). Among land uses, highest contents were found in orchard lands (1.53 and 1.10%) followed by agri-silvi-horti lands (1.10 and 1.03%), whereas, lowest (0.50 and 0.43%) were observed in scrub lands in 0.0-0.15 and 0.15-0.30 m layers, respectively. This may be due to relatively higher ground biomass turn over and organic carbon in perennial system compared to cropped land.

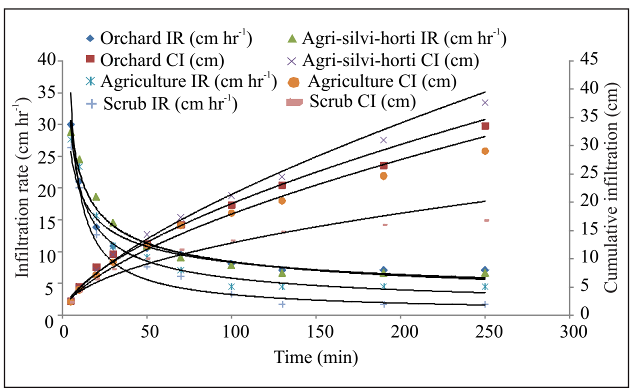

Fig. 3. Infiltration characteristics of soils under different land uses

Soils were low in available N, high in P and medium in K in all land uses (Table 3). However, scrub land had low available K status. Among land uses, comparatively higher N contents were recorded in orchard lands (248.2 and 210.7 kg ha^{-1}) in both the depths inevitably due to regular additions of fertilizers and farm yard manure. Higher available P contents were recorded in agricultural lands (54.6 and 42.7 kg ha^{-1}) which may be attributed to higher fertilizer P accumulations in the surface layers because of its low mobility to lower depths. The orchard lands recorded comparatively higher K contents (247.4 and 176.9 kg ha^{-1}) in both the depths. Lowest K contents (134.0 and 114.2 kg ha^{-1}) were recorded in scrub lands in both the layers which could be due to its depletion partly by vegetation removal and partly by leaching as soils in these lands are coarser in texture.

Erodibility status of the soils under different land uses

Soil erodibility is a quantitative measure of soil's inherent susceptibility to erosion by wind and water. Many earlier workers have used both ER and DR to assess the erosional behaviour of soils. Erodibility indices *viz.*, DR, ER, EI, MWD and WSA (>0.25 mm) were employed to assess the erosional behavior soils under different land uses. According to the criterion of Middleton *et al.* (1930), soils having dispersion ratio > 15 are erodible in nature and accordingly soils under all land uses except surface soils of orchards were found to be highly erodible (Table 4). Among the land uses, orchard lands had least DR values as compared to other land uses which can be ascribed to their higher water retention and organic carbon contents thus imparting more stability to soil aggregates. Vegetated lands (forest lands) exhibited lower values of DR as compared to other land uses (Chakrabarti, 1971; Dabral *et al.,* 2001). Comparatively higher DR values of soils under agricultural and scrub lands may due to lower organic carbon contents in these lands and poor aggregation and also the surface layer under agricultural lands become loose by continuous tillage operations.

All soils under different land uses in the micro-watershed had more than 30% 'silt + clay', hence, DR can be used as an effective index of erodibility for all land uses

Table: 3
Chemical properties of soils under different land uses

Land uses	pH (1:2)		OC (%)		N (kg ha^{-1})		P (kg ha^{-1})		K (kg ha^{-1})	
	Soil depths (m)									
	0.0-0.15	0.15-0.30	0.0-0.15	0.15-0.30	0.0-0.15	0.15-0.30	0.0-0.15	0.15-0.30	0.0-0.15	0.15-0.30
Orchard	6.65	6.76	1.23	1.10	248.2	210.7	24.9	20.4	247.4	176.9
Agri-silvi-horti	6.68	6.69	1.10	1.03	236.4	198.1	32.4	22.6	239.1	164.1
Agriculture	6.70	6.74	0.80	0.60	220.0	189.5	54.6	42.9	213.2	165.9
Scrub	7.21	7.41	0.50	0.43	193.3	188.2	47.1	31.1	134.0	114.2
Mean	6.80	6.90	0.90	0.79	224.4	196.6	39.7	29.2	208.4	155.3
LSD	NS	NS	0.30	0.37	10.87	8.90	NS	NS	23.23	39.96

Significant at 5% level

Table: 4
Erodibility indices of soils under different land uses

Land uses	DR		ER		EI	
	Soil depths (m)					
	0.0-0.15	0.15-0.30	0.0-0.15	0.15-0.30	0.0-0.15	0.15-0.30
Orchard	14.7	15.1	15.1	18. 9	14.8	12.1
Agri-silvi-horti	17.3	17.5	18.3	21.3	16.50	15.2
Agriculture	20.4	21.4	21.9	27.8	24.0	17.3
Scrub	19.8	21.5	21.6	24.3	19.1	15.9
Mean	18.1	18.9	23.1	18.9	18.6	5.7
LSD	2.5	2.4	4.6	2.4	9.6	10.1

Significant at 5% level

taken under study. Bryan (1967) have reported that DR could be used as an effective index only when the soil is composed of at least 30% 'silt + clay'. It loses its utility as the amount of 'silt + clay' in a soil falls below 30%. Both DR and ER were found to be positively correlated and significant levels were observed in soils under orchard, agriculture and scrub lands with 'r' values of 0.86, 0.61 and 0.69, respectively.

Agricultural lands recorded highest ER (27.85 and 21.87) followed by scrub lands (24.34 and 21.65) in 0.0-0.15 and 0.15-0.30 m soil depths, respectively (Table 4). In respective soil depths, lowest ER being 8.89 and 15.06 was recorded in orchard lands. This suggests that soils under orchards lands are comparatively less erodible and soils under scrub and agricultural lands are more susceptible to erosion. However, considering 10 as threshold value between erodible and non-erodible soils, all land uses according to ER were erodible in nature. ER was found to be positively correlated with sand in all land uses (r= 0.77, 0.66, 0.43 and 0.32) and negatively with silt (-0.59, -0.34, -0.84 and -0.08) and clay (-0.93,-0.19,-0.88 and -0.49) in orchard, agri-silvi-horti, agriculture and scrub lands, respectively. Similar relations of sand, silt and clay with ER have also been reported earlier by Bhatia and Vardani (1982). Both DR and ER in soils under different land uses increased with depth making the subsurface layer more erodible as compared to surface layer. This increasing trend of susceptibility to erosion seems to be due to decrease in organic carbon with profile depth.

Erosion index (EI) proposed by Sahi *et al*. (1977) is considered as an reliable index of soil erodibility. Among different land uses, EI was found to be highest (24.0 and 17.3) under agricultural lands and lowest (14.8 and 12.1) under orchard land in both the soil layers (Table 4). Considering 2.8, a threshold value between erodible and non-erodible soils, all land uses were found to be erodible and as per the erodibility indices, different land uses followed the order as: Scrubs > agriculture > agri-silvi-horti > orchard land. ER and EI were found to be significantly and positively correlated in all the land uses and correlation coefficients (r-values) were 0.92, 0.78, 0.96 and 0.81 for orchard, agri-silvi-horti, agricultural and scrub lands, respectively. Thus, for determination of erodibility of soil, EI can be safely used in place of ER as determination of EI is easier and less time consuming than ER.

4. CONCLUSIONS

The foregoing discussion led to a conclusion that physico-chemical properties *viz.*, texture, WSA, and MWD play significant and positive role in water retention and susceptibility of soil to erosion. Different erodibility indices *viz.*, DR, ER and EI were found equally good for assessing the erodibility of soils and can be used interchangeably. Available N, P, K status of the soils under different land uses led to a conclusion that most of the soils were poor in available N, very high in P and low to medium in K status. The study suggested that regular N and K fertilization is necessary in agricultural and orchard lands for better crop production. There is a need to adopt suitable soil and water conservation measures in agricultural and orchard lands to sustain their health for sustaining the crop production by checking their susceptibility to erosion. Agricultural, orchard and agri-silvi-horti lands need to be supplied with sufficient quantity of organic matter and recommended doses of N and K fertilizers to improve soil aggregation, moisture retention and nutrient status. Scrub lands need to be replaced by more effective soil and water resource conserving systems like agro-forestry, agri-horticulture and silvi-pasture.

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