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Soil carbon storage potential of different land use systems in upstream catchment area of Gobind Sagar reservoir, Himachal Pradesh

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ABSTRACT

Four land use systems (agriculture, agroforests, forest and grassland) from the upstream Gobind Sagar reservoir in Bilaspur district of Himachal Pradesh were studied to analyse their effect on soil carbon status. Randomly distributed 25 sites were selected in 14 km distance from the reservoir to collect soil samples (0-30 cm soil depth) from selected system. Elevation of the study sites ranged from 542 to 1024 m asl. Forest system recorded lower soil pH (6.76±0.17) and EC (0.15±0.029), soil bulk density and higher organic carbon (%) in comparison to other systems. Sites closer to the reservoir showed lower soil bulk density ($p<0.05$) and higher organic carbon ($p<0.01$). Higher soil organic carbon (85.34 t ha^{-1}) was recorded in forest; however, agroforests (56.25 t ha^{-1}) and grassland (55.24 t ha^{-1}) systems were statistically comparable. Principal component analysis (PCA) was employed to see the relationship between different land use systems and soil physico-chemical properties. First component accounted for 36.6% variance and the highest positive loadings were found with organic carbon (%) followed by soil organic carbon (t ha^{-1}) and sand (%). Contribution from second component to the total variance was 26.3% and the highest positive loadings were found with silt (%) followed by EC, pH and clay (%), whereas higher negative loading was found with sand (%).

1. INTRODUCTION

Soils are critically important in determining changes in global carbon cycle because they serve as a link between the atmosphere, vegetation and oceans. The carbon in soil is available in organic and inorganic forms. It is stored for long time and serve the largest terrestrial carbon reservoir. Carbon sequestration and its storage in the soil is necessary for long term mitigation of carbon and combat climate change problems, thereby reducing concentration of atmospheric carbon. Soil Organic Carbon (SOC) in the top one meter of soil comprises about $3/4^{th}$ of the earth's terrestrial carbon (Koul and Panwar, 2012), where SOC is 3 times more than the size of the atmospheric pool (760 Gt) and about 4.5 times the size of the biotic pool of 560 Gt (Grace *et al.,* 2012). Also, it is an important attribute of soil quality and productivity. It maintains fertility, water retention and plant production in terrestrial ecosystems. It also provides other important benefits in terms of increased soil fertility and environmental quality (Katyal *et al.,* 2001; Venkanna *et al.,* 2014).

Natural as well as man made water reservoirs accelerate the rate of land use change and influence soil properties. The availability of natural resources and other facilities prompts people for adopting commercial and productive systems. The excess human and livestock pressure on existing vegetation systems also cause depletion of SOC and productivity of soils. The changes in SOC over time depend on carbon added through organic matter and its rate of decompostion. Under undisturbed natural land use systems, inputs of carbon from litter fall and root biomass are cycled by output through erosion, organic matter decomposition, and leaching. The potential carbon sequestration is controlled primarily by pedological factors that set the physico-chemical maximum limit to storage of carbon in the soil. Soil organic carbon dynamics and soil carbon flux can be significantly influenced by different land use systems and soil management practices (Tian *et al.,* 2002). Venkanna *et al.* (2014) reported 0.7 and 2.1 Gt carbon loss yr^{-1} in tropical soils due to the land-use change (deforestation) and related land-change processes (erosion, tillage operations, biomass burning, excessive fertilizers, residue removal and drainage of peat lands).

Therefore, conservation of SOC for improving productivity of tropical soils on sustainable basis is prime requirement. Keeping this context in mind, the present study was undertaken to estimate the physico-chemical properties of soil in four land use systems in upstream catchment area of Gobind Sagar reservoir in Himachal Pradesh.

2. MATERIALS AND METHODS

Study Area

In upstream catchment area of Gobind Sagar reservoir of Satluj basin (Satluj upper sub-basin; Code: 13) at Bilaspur district, Himachal Pradesh (Fig.1 and Table 1) four types of land use systems (agriculture, agroforests, forest and grassland) are protuberant. In case of forest, uneven aged sub-tropical pine and tropical mixed forests (of average 520 trees ha^{-1}) are prominent, whereas agri-silviculture, agri-horticulture, agri-silvi-horticulture, agri-

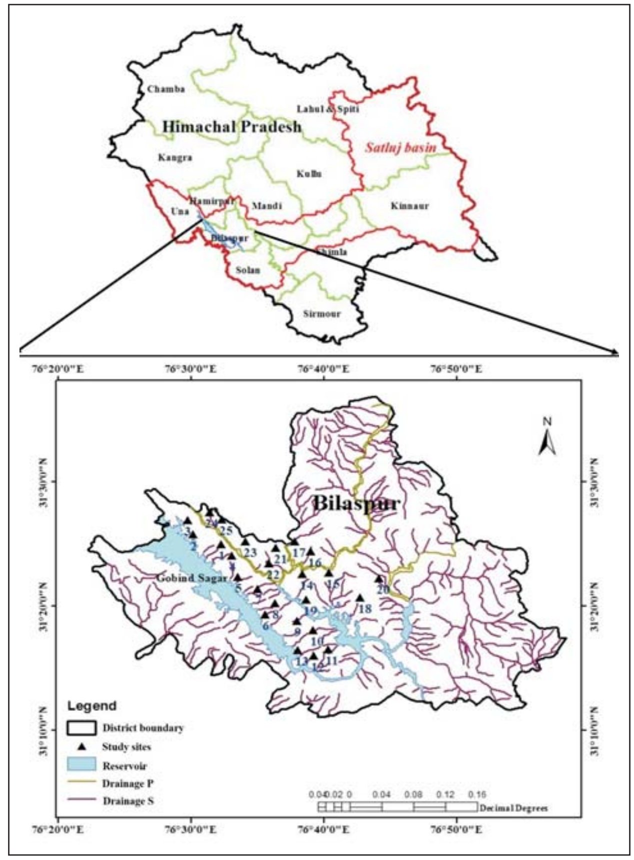


Fig. 1. Location of the study sites

Table: 1
Latitude, longitude, elevation and soil texture of the study sites

Site	Lat-long (degree, decimal, seconds)	Elevation (m)	Texture		
			Clay (%)	Silt (%)	Sand (%)
D_1-2-Jai Shri Devi	31^{0}25'27.2"N and 76^{0}29'57.3"E	585	14.83	34.75	50.42
D_1-3-Badgaon	31^{0}26'43.9"N and 76^{0}29'53.5"E	612	13.00	31.08	55.92
D_1-5-Jaddu	31^{0}22'22.1"N and 76^{0}33'25.0"E	565	6.75	32.92	60.33
D_1-6-Malroan	31^{0}19'22.5"N and 76^{0}35'42.6"E	615	9.75	30.83	59.42
D_1-13-Dhanola	31^{0}16'28.20"N and 76^{0}37'58.4"E	542	17.67	36.00	46.33
D_1-19-Fugogh	31^{0}20'28.80"N and 76^{0}38'47.86"E	589	10.17	30.58	59.25
D_2-7-Tihri	31^{0}21'15.1"N and 76^{0}35'07.4"E	890	9.08	30.17	60.75
D_2-8-Jhunjnu	31^{0}20'03.2"N and 76^{0}36'21.3"E	924	15.17	26.58	58.25
D_2-9-Paploh	31^{0}18'34.9"N and 76^{0}37'55.5"E	1001	11.42	27.17	61.42
D_2-10-Silwin	31^{0}18'21.4"N and 76^{0}39'06.7"E	665	7.58	31.08	61.33
D_2-11-Kukrehar	31^{0}16'25.1"N and 76^{0}39'43.3"E	1024	13.17	27.08	59.75
D_2-12-Kharli	31^{0}16'02.8"N and 76^{0}39'19.9"E	760	7.00	33.08	59.92
D_3-1-Jol	31^{0}24'58.2"N and 76^{0}32'23.5"E	788	10.08	33.33	56.58
D_3-4-Gangloh	31^{0}23'58.5"N and 76^{0}33'11.0"E	826	8.83	29.58	61.58
D_3-18-Raily	31^{0}20'43.91"N and 76^{0}43'22.72"E	618	11.17	27.67	61.17
D_4-14-Beharan	31^{0}22'41.50"N and 76^{0}38'26.80"E	729	11.17	26.67	62.17
D_4-22-Kuthera	31^{0}23'26.70"N and 76^{0}36'02.70"E	615	14.92	28.00	57.08
D_4-24-Talai	31^{0}27'17.95"N and 76^{0}31'25.31"E	721	11.75	30.17	58.08
D_5-15-Ser	31^{0}22'49.00"N and 76^{0}40'24.70"E	665	8.08	26.92	65.00
D_5-25-Jhabola	31^{0}27'0.20"N and 76^{0}32'13.50"E	722	14.25	25.00	60.75
D_6-20-Seru Salasi	31^{0}22'15.99"N and 76^{0}43'7.726"E	681	13.42	28.00	58.58
D_6-21-Malari	31^{0}24'46.00"N and 76^{0}36'32.20"E	613	10.08	22.17	67.75
D_6-23-Gujrera	31^{0}25'09.40"N and 76^{0}34'15.30"E	687	19.67	25.42	54.92
D_7-16-Dhroti	31^{0}24'47.70"N and 76^{0}39'16.30"E	638	11.08	23.50	65.42
D_7-17-Singaswin	31^{0}25'12.60"N and 76^{0}37'38.30"E	662	11.75	23.00	65.25

horti-silviculture agroforests were identified. The study was carried out in these four land use systems by selecting 25 sites randomly at 14 kms distance from the reservoir. The sites were located at 31˚16'02.8" to 31˚27'17.95"N latitude and 76˚29'53.5" to 76˚43'22.72"E longitude. An elevation of the sites ranges from 542 to 1024 m asl (above sea level); however, most of the area falls below 700 m asl. The temperature in the area ranges from as low as 0.3^0C to as high as 37^0C. Precipitation in the past ten years (2005-2014) varied from 885.4 to 1364.6 mm. The area is gently sloping and soils are shallow, light textured, low in fertility and neutral in reaction with pH ranging from 6.33 to 7.83.

Soil Sampling and Analysis

The sites were selected in the range of 14 kms from reservoir, on the basis of their distance (D) from reservoir, elevation and soil texture class. Composite (500 g) soil samples were collected from 0-30 cm depth from every land use system at each study sites. A total of 100 composite soil samples were air dried and passed through 2 mm sieve, and used for determination of selected soil attributes.

Soil particle size was determined by sieving and pipette methods (Gee and Bauder, 1986). Soil pH and electrical conductivity was determined by using pH meter and electrical conductivity meter, respectively (Jackson, 1973). Bulk density (BD) of soil was estimated by weighing bottle method (Singh, 1980). Organic carbon (%) was determined by using the method of oxidizable organic carbon given by Walkley and Black (1934). Soil organic carbon (SOC) in t ha^{-1} was determined following Joa Carlos *et al.* (2001).

Statistical Analysis

Data analysis was carried out using JMP-SAS software package. The basic statistical values *i.e.,* standard deviation (SD) was calculated for each soil parameter under each system at all study sites. Data for each system were analyzed by analysis of variance (ANOVA) technique. The significant differences between systems for all the soil parameters were compared with the Tukey-Kramer HSD test ($p<0.05$). To best explore the available data, we conducted the multivariate statistical analysis, PCA by using JMP SAS software package for four land use systems (25 study site). Total eight soil attributes were used for PCA analysis at 5% level of statistical significance.

3. RESULTS AND DISCUSSION

Soil pH plays an important role on microbial activity in soil, decomposition of organic matter and release of nutrient (Arunachalam and Pandey, 2003; Kemmitt *et al.,* 2006). It acts as an important factor in many soil improvement processes (Khanna, 1998). Rhizosphere acidification increases the solubility of soil P under forest and tree based systems, which is associated with the balance in cation and anion uptake and the production of protons in nitrification (Soromessa *et al.,* 2004). In present study, significantly higher pH was recorded in soil of Jhunjnu site, whereas lower pH at Kukrehar for agriculture/field soil. In case of agroforests, pH did not varied significantly for soils of different study sites; however, soils of agroforest from Paploh site showed lower and Raily exhibited slightly higher soil pH values. Significant lower soil pH was recorded under forest soils of Tehri as compared to other sites, whereas it was statistically similar with forest soils of Jhunjnu and Singaswin. Grasslands of Beharan site recorded lower soil pH values than grasslands of other sites (Table 2). In case of different systems, forest soils showed significant lower pH values whereas, soils of agroforests and grasslands were statistically similar (Fig. 2).

The sites with higher elevation had lower soil pH which might be due to high rate of soil erosion. Runoff water carries away soil nutrients and most of the bases resulting in lowering of soil pH (Mishra, 2011). The decomposition rate of crop residue and applied organic manure is quite high under agriculture/crop fields due to tillage practices; it leads to higher soil pH (Mishra, 2011). The reduction in pH of forest and tree based system soils is mainly due to accumulation of organic matter and release of organic acids through their subsequent slow decomposition rate (Yadav *et al.,* 2008; Gangopadhyay *et al.,* 2011; Gairola *et al.,* 2012). Peng *et al*. (2008) stated that the increase in acidity of soils is generally linked with a decrease in decomposition rate of organic matter, although the extent of decrease varies with nature of the organic materials.

Electrical conductivity (EC) of soil is generally used to determine soil salinity and serve as a measure of soluble nutrients in soil (Kumar *et al.,* 2012). Several authors reported relation between soil EC and the variation in production of vegetation systems. Soil EC (dS m^{-1}) varied significantly in different study sites and land use systems (Table 2 and Fig. 2). Agriculture system of Paploh recorded lower soil EC (0.14), whereas Kukrehar sites showed lower soil EC for agroforests (0.11), forest (0.09) and grassland (0.13). The sites located away from reservoir and at higher elevation recorded lower soil EC. Soils of forest system (0.15) recorded significantly lower EC followed by agroforests (0.18), grassland (0.20) and agriculture (0.22). Lower soil EC value indicates the lower amount of salts present in solution. The sites having lower pH showed significant lower soil EC values for forest and tree based agroforestry systems (Barros and Chaves, 2014). Similar results were reported by Zuo *et al.* (2009), Devi *et al*. (2013) and Shah *et al.* (2013).

Bulk density (BD in g cc^{-1}) is a measure of compactness which is associated with water holding capacity of soil (Upadhyaya *et al.,* 2003; Paudel and Sah, 2003; Dadhwal *et al.,* 2011), and is widely used for determining soil organic carbon (t ha^{-1}). It may vary in different land use systems due

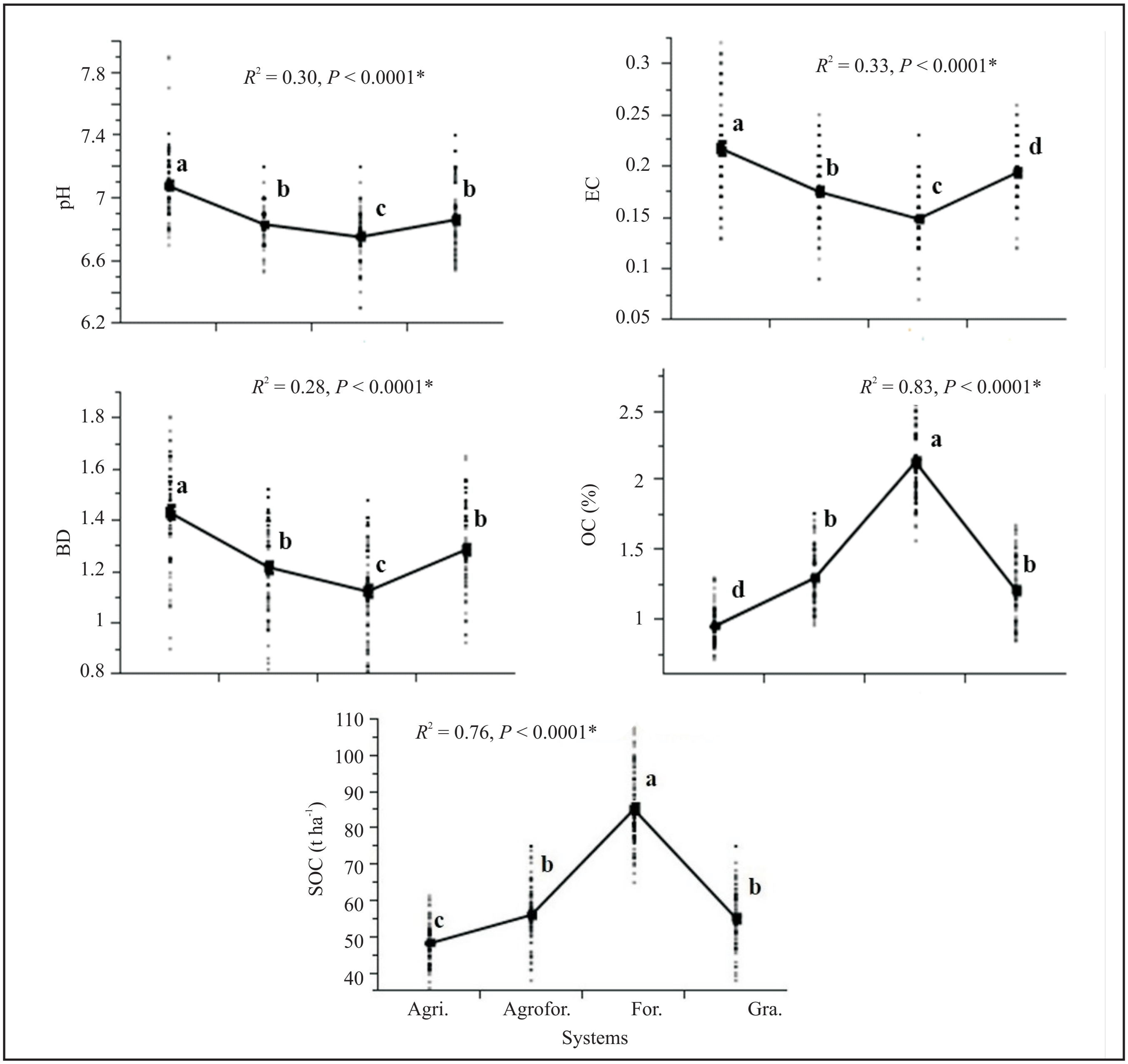
Table: 2
Soil pH and EC (dSm^{-1}) under different land use systems of study sites (values represent mean ± SD)

Site Number-Name	Land Use systems							
	Agriculture		Agroforests		Forest		Grasslands	
	pH	EC	pH	EC	pH	EC	pH	EC
D$_1$-2-Jai Shri Devi	7.31±0.10$_{bc}$	0.29±0.015$_{a}$	6.96±0.21$_{a}$	0.21±0.021$_{a}$	6.94±0.14$_{a}$	0.19±0.015$_{a}$	7.12±0.18$_{a}$	0.23±0.021$_{a}$
D$_1$-3-Badgaon	7.08±0.16$_{bc}$	0.23±0.030$_{ab}$	6.84±0.13$_{a}$	0.18±0.020$_{a}$	6.68±0.07$_{ab}$	0.19±0.040$_{a}$	6.90±0.04$_{ab}$	0.21±0.032$_{a}$
D$_1$-5-Jaddu	7.23±0.12$_{bc}$	0.28±0.025$_{a}$	6.97±0.06$_{a}$	0.20±0.021$_{a}$	6.96±0.21$_{a}$	0.16±0.015$_{a}$	7.00±0.17$_{a}$	0.21±0.015$_{a}$
D$_1$-6-Malroan	7.14±0.15$_{bc}$	0.24±0.035$_{ab}$	6.79±0.03$_{a}$	0.21±0.025$_{a}$	6.66±0.05$_{ab}$	0.17±0.021$_{a}$	6.86±0.08$_{ab}$	0.21±0.015$_{a}$
D$_1$-13-Dhanola	7.21±0.11$_{bc}$	0.26±0.030$_{a}$	6.90±0.10$_{a}$	0.21±0.038$_{a}$	6.87±0.11$_{a}$	0.16±0.010$_{a}$	6.90±0.18$_{ab}$	0.22±0.025$_{a}$
D$_1$-19-Fugogh	7.18±0.09$_{bc}$	0.25±0.032$_{a}$	6.97±0.06$_{a}$	0.19±0.021$_{a}$	6.94±0.05$_{a}$	0.18±0.025$_{a}$	6.91±0.03$_{ab}$	0.23±0.010$_{a}$
D$_2$-7-Tihri	6.91±0.20$_{bc}$	0.18±0.030$_{ab}$	6.71±0.05$_{a}$	0.15±0.035$_{ab}$	6.33±0.06$_{c}$	0.14±0.020$_{ab}$	6.64±0.07$_{ab}$	0.18±0.006$_{a}$
D$_2$-8-Jhunjnu	7.83±0.11$_{a}$	0.17±0.032$_{ab}$	6.67±0.14$_{a}$	0.14±0.015$_{ab}$	6.53±0.06$_{bc}$	0.12±0.006$_{ab}$	6.63±0.05$_{ab}$	0.16±0.015$_{ab}$
D$_2$-9-Paploh	6.87±0.07$_{bc}$	0.14±0.010$_{b}$	6.65±0.10$_{a}$	0.13±0.036$_{ab}$	6.62±0.08$_{b}$	0.10±0.015$_{ab}$	6.62±0.05$_{ab}$	0.15±0.030$_{ab}$
D$_2$-10-Silwin	7.10±0.13$_{bc}$	0.23±0.015$_{ab}$	6.80±0.10$_{a}$	0.19±0.015$_{ab}$	6.89±0.10$_{a}$	0.18±0.021$_{a}$	7.00±0.10$_{a}$	0.22±0.038$_{a}$
D$_2$-11-Kukrehar	6.84±0.14$_{c}$	0.15±0.015$_{ab}$	6.66±0.11$_{a}$	0.11±0.021$_{b}$	6.61±0.14$_{b}$	0.09±0.015$_{b}$	6.73±0.06$_{ab}$	0.13±0.015$_{b}$
D$_2$-12-Kharli	7.07±0.06$_{bc}$	0.20±0.015$_{ab}$	6.80±0.10$_{a}$	0.17±0.025$_{ab}$	6.82±0.07$_{a}$	0.16±0.026$_{a}$	6.81±0.07$_{ab}$	0.20±0.044$_{a}$
D$_3$-1-Jol	7.11±0.04$_{bc}$	0.19±0.015$_{ab}$	6.83±0.12$_{a}$	0.18±0.021$_{a}$	6.76±0.06$_{a}$	0.17±0.021$_{a}$	6.87±0.09$_{ab}$	0.21±0.015$_{a}$
D$_3$-4-Gangloh	6.98±0.11$_{bc}$	0.19±0.015$_{ab}$	6.78±0.04$_{a}$	0.16±0.025$_{ab}$	6.76±0.05$_{a}$	0.14±0.010$_{ab}$	6.65±0.06$_{ab}$	0.19±0.10$_{a}$
D$_3$-18-Raily	7.03±0.06$_{bc}$	0.25±0.051$_{a}$	7.00±0.10$_{a}$	0.20±0.010$_{a}$	6.80±0.07$_{a}$	0.15±0.020$_{a}$	7.09±0.13$_{a}$	0.22±0.015$_{a}$
D$_4$-14-Beharan	6.98±0.10$_{bc}$	0.21±0.021$_{ab}$	6.80±0.10$_{a}$	0.16±0.012$_{ab}$	6.71±0.10$_{a}$	0.14±0.020$_{ab}$	6.56±0.03$_{b}$	0.18±0.026$_{a}$
D$_4$-22-Kuthera	7.11±0.10$_{bc}$	0.26±0.046$_{a}$	6.93±0.06$_{a}$	0.21±0.021$_{a}$	6.83±0.05$_{a}$	0.14±0.021$_{ab}$	7.07±0.18$_{a}$	0.21±0.010$_{a}$
D$_4$-24-Talai	6.97±0.21$_{bc}$	0.20±0.031$_{ab}$	6.80±0.10$_{a}$	0.19±0.020$_{a}$	6.92±0.09$_{a}$	0.16±0.015$_{a}$	6.85±0.11$_{ab}$	0.20±0.021$_{a}$
D$_5$-15-Ser	7.01±0.22$_{b}$	0.27±0.031$_{a}$	6.93±0.06$_{a}$	0.19±0.025$_{a}$	6.85±0.05$_{a}$	0.16±0.026$_{a}$	6.81±0.04$_{ab}$	0.20±0.020$_{a}$
D$_5$-25-Jhabola	7.03±0.15$_{bc}$	0.22±0.049$_{ab}$	6.81±0.10$_{a}$	0.17±0.021$_{ab}$	6.72±0.08$_{a}$	0.13±0.010$_{ab}$	7.11±0.22$_{a}$	0.19±0.006$_{a}$
D$_6$-20-Seru Salasi	7.08±0.10$_{bc}$	0.27±0.047$_{a}$	6.70±0.10$_{a}$	0.22±0.025$_{a}$	6.81±0.07$_{a}$	0.15±0.012$_{a}$	6.99±0.10$_{ab}$	0.18±0.010$_{a}$
D$_6$-21-Malari	6.93±0.10$_{bc}$	0.18±0.012$_{ab}$	6.97±0.06$_{a}$	0.18±0.026$_{a}$	6.85±0.05$_{a}$	0.13±0.010$_{ab}$	7.17±0.23$_{a}$	0.20±0.021$_{a}$
D$_6$-23-Gujrera	7.24±0.06$_{bc}$	0.27±0.050$_{a}$	6.87±0.06$_{a}$	0.19±0.021$_{a}$	6.82±0.11$_{a}$	0.15±0.015$_{a}$	7.08±0.16$_{a}$	0.18±0.010$_{a}$
D$_7$-16-Dhroti	6.88±0.11$_{bc}$	0.19±0.020$_{ab}$	6.90±0.09$_{a}$	0.15±0.01$_{ab}$	6.75±0.05$_{a}$	0.14±0.015$_{ab}$	6.67±0.05$_{ab}$	0.16±0.006$_{ab}$
D$_7$-17-Singaswin	6.91±0.10$_{bc}$	0.16±0.015$_{ab}$	6.89±0.04$_{a}$	0.14±0.015$_{ab}$	6.53±0.06$_{bc}$	0.15±0.020$_{a}$	6.64±0.08$_{ab}$	0.19±0.020$_{a}$
Mean	7.08±0.22	0.22±0.051	6.84±0.13	0.18±0.034	6.76±0.17	0.15±0.029	6.87±0.21	0.20±0.029

Values followed by a different lowercase letter within system are significantly different (p<0.05)

to variation in quantity of organic matter addition to the soil (Lal, 2005). In the present study, soils of Kukrehar site showed higher bulk density (g cc^{-1}) for all land use systems (Table 3). Lower bulk density was recorded at Jai Shri Devi (1.07); however, it was statistically at par with Jaddu (1.12), Dhanola (1.16), Fugogh (1.18) sites for agriculture system. In case of agroforests and forest systems, lower bulk density was recorded at soils of Jai Shri Devi sites (0.93 and 0.87, respectively). Sites closer to the reservoir recorded lower soil bulk density for grasslands. Jai Shri Devi site showed lower soil bulk density (1.00); however, it was statistically similar with Jaddu, Malroan, Dhanola, Fugogh, Singaswin, Silwin and Badgaon sites for grassland. Soil bulk density (g cc^{-1}) was significantly lower (1.13) in forest as compared to other land use systems. However, agroforests (1.22) and grassland (1.29) systems were statistically similar (Fig. 2). Soil compactness may decrease because of adding more organic matter/litter under forest and tree based systems (Lal, 2005; Dieleman *et al.,* 2013; Devi *et al*., 2013; Shah *et al.,* 2013). Dadhwal *et al.* (2011) and Mandal *et al.* (2010) reported similar results for scrub land, terraced agriculture fields and forest system. The growth of herb species improved near reservoir may be due to availability of water resources and less pressure of grazing/browsing animals.

High organic carbon in soil assists to improve soil physico-chemical properties (Venkanna *et al.,* 2014). Organic carbon in soil is mainly associated with quantity of organic matter addition and the rate of organic matter decomposition, whereas rate of organic matter decomposition depends on several climatic (rainfall and temperature), edaphic (soil temperature), biotic (microbial activities) and topographic factors (aspect and slope). In the present study, organic carbon (%) in soil ranged from 0.77 to 1.17, 1.06 to 1.66, 1.66 to 2.42 and 1.01 to 1.59 for agriculture, agroforests, forest and grassland soils, respectively at different study sites (Table 3). Agriculture of Jhabola, agroforests and forest soils of Kukrehar showed lower organic carbon, whereas Paploh site showed lower organic carbon for grasslands. Organic carbon in soil was significantly (R^2 = 0.83, P < 0.0001) affected by different land use systems. Forest soils (2.14%) recorded significantly higher organic carbon followed by agroforests (1.30%), grassland (1.29%) and agriculture (0.95%) systems, whereas organic carbon in soils of agroforests and grasslands were statistically similar (Table 3 and Fig. 2). Lower organic carbon in agriculture fields may be due to



The different lower case letters represent a significant difference among the systems for each parameter (*P*<0.05, Tukey-Kramer HSD test); Where, Agri. is Agriculture; Agrofor. is Agroforests; For. is Forest and Gra. is Grassland

Fig. 2. Soil properties influenced by different land use systems

tillage practices which made favourable conditions for organic matter decomposition as compared to forest system (Sanchez *et al.,* 2002; Manley *et al.,* 2005; Yadav *et al.,* 2008; Mishra, 2011). Forest and other tree based systems incorporate high amount of litter to the soil and improve organic carbon and nutrient status of soil (Mandal *et al.* 2010; Dadhwal *et al.* 2011; Koul and Panwar, 2012).

Soil organic carbon (SOC) is a largest terrestrial carbon pool. It plays very important role in global carbon cycle (Lal, 2005) and is an important indicator of soil heath and its productivity (Bini *et al.,* 2013; Venkanna *et al.,* 2014). Land use pattern of the particular area creates variation due to resource availability which causes variation in SOC (t ha^{-1}) (Dadhwal *et al.* 2011; Mandal *et al.* 2010; Goswami *et al.,* 2014). In the present study, SOC varied non-significantly at different study sites (Table 4). Their mean values ranged from 43.51 to 53.79 t ha^{-1} for agriculture, 44.54 to 62.81 t ha^{-1} for agroforests, 75.16 to 97.41 t ha^{-1} for forest and 46.91 to 63.89 t ha^{-1} for grasslands from different study sites. Higher SOC (t ha^{-1}) was recorded from Malari (53.79±4.73), whereas lower from Jhabola (43.51±6.73) site for agriculture soils. In case of agroforests, soils from Raily

Table: 3
Soil bulk density (g cc^{-1}) and organic carbon (%) under different land use systems of study sites (values represent mean ± SD)

Site Number-Name	Land Use systems							
	Agriculture		Agroforests		Forest		Grasslands	
	BD	OC	BD	OC	BD	OC	BD	OC
D$_1$-2-Jai Shri Devi	1.07±0.18$_c$	1.17±0.10$_a$	0.93±0.09$_b$	1.66±0.13$_a$	0.87±0.05$_b$	2.42±0.12$_a$	1.00±0.05$_c$	1.59±0.12$_a$
D$_1$-3-Badgaon	1.30±0.13$_b$	1.03±0.06$_{ab}$	1.17±0.17$_{ab}$	1.48±0.07$_a$	0.97±0.10$_{ab}$	2.38±0.23$_a$	1.24±0.07$_{bc}$	1.40±0.06$_a$
D$_1$-5-Jaddu	1.12±0.16$_{bc}$	1.15±0.13$_a$	0.94±0.09$_b$	1.62±0.08$_a$	0.89±0.06$_b$	2.43±0.08$_a$	1.03±0.12$_c$	1.52±0.10$_a$
D$_1$-6-Malroan	1.32±0.24$_b$	1.04±0.05$_{ab}$	1.06±0.22$_b$	1.49±0.06$_a$	0.96±0.18$_{ab}$	2.35±0.19$_a$	1.13±0.07$_c$	1.35±0.06$_a$
D$_1$-13-Dhanola	1.16±0.08$_{bc}$	1.13±0.12$_a$	0.97±0.05$_b$	1.66±0.11$_a$	0.91±0.08$_b$	2.37±0.18$_a$	1.06±0.11$_c$	1.49±0.08$_a$
D$_1$-19-Fugogh	1.18±0.06$_{bc}$	1.12±0.13$_a$	1.02±0.04$_b$	1.55±0.07$_a$	0.92±0.10$_b$	2.40±0.25$_a$	1.11±0.09$_c$	1.54±0.09$_a$
D$_2$-7-Tihri	1.56±0.08$_a$	0.87±0.05$_{ab}$	1.30±0.10$_{ab}$	1.27±0.13$_{ab}$	1.20±0.12$_a$	2.18±0.11$_b$	1.42±0.13$_a$	1.25±0.08$_{ab}$
D$_2$-8-Jhunjnu	1.62±0.09$_a$	0.85±0.04$_{ab}$	1.39±0.04$_a$	1.14±0.06$_{ab}$	1.34±0.07$_a$	1.86±0.10$_{ab}$	1.51±0.05$_a$	1.08±0.12$_b$
D$_2$-9-Paploh	1.68±0.10$_a$	0.82±0.03$_b$	1.45±0.06$_a$	1.07±0.07$_b$	1.36±0.04$_a$	1.83±0.14$_{ab}$	1.56±0.08$_a$	1.01±0.19$_b$
D$_2$-10-Silwin	1.25±0.19$_b$	0.99±0.07$_{ab}$	1.07±0.03$_b$	1.46±0.05$_a$	0.97±0.19$_{ab}$	2.36±0.17$_a$	1.15±0.06$_c$	1.37±0.23$_a$
D$_2$-11-Kukrehar	1.73±0.07$_a$	0.77±0.06$_{ab}$	1.46±0.07$_a$	1.06±0.10$_b$	1.39±0.08$_a$	1.66±0.11$_b$	1.57±0.07$_a$	1.03±0.16$_b$
D$_2$-12-Kharli	1.42±0.11$_{ab}$	0.93±0.05$_{ab}$	1.17±0.13$_{ab}$	1.33±0.13$_a$	1.17±0.11$_{ab}$	2.33±0.19$_a$	1.25±0.05$_{bc}$	1.30±0.13$_a$
D$_3$-1-Jol	1.48±0.07$_{ab}$	0.99±0.06$_{ab}$	1.26±0.12$_{ab}$	1.30±0.12$_a$	1.16±0.10$_{ab}$	2.28±0.15$_a$	1.32±0.07$_b$	1.19±0.12$_{ab}$
D$_3$-4-Gangloh	1.59±0.05$_a$	0.89±0.05$_{ab}$	1.32±0.11$_{ab}$	1.16±0.10$_{ab}$	1.28±0.11$_a$	2.13±0.04$_b$	1.45±0.10$_a$	1.05±0.10$_b$
D$_3$-18-Raily	1.33±0.08$_b$	1.00±0.19$_{ab}$	1.30±0.12$_{ab}$	1.34±0.11$_a$	1.14±0.08$_{ab}$	2.13±0.18$_b$	1.29±0.08$_{ab}$	1.14±0.13$_{ab}$
D$_4$-14-Beharan	1.53±0.12$_a$	0.84±0.03$_b$	1.35±0.07$_a$	1.11±0.05$_b$	1.22±0.17$_a$	1.86±0.11$_{ab}$	1.40±0.14$_a$	1.03±0.14$_b$
D$_4$-22-Kuthera	1.44±0.08$_{ab}$	0.93±0.08$_{ab}$	1.30±0.13$_{ab}$	1.30±0.09$_a$	1.17±0.18$_{ab}$	2.08±0.10$_b$	1.29±0.10$_{ab}$	1.11±0.13$_{ab}$
D$_4$-24-Talai	1.50±0.05$_a$	0.95±0.12$_{ab}$	1.29±0.13$_{ab}$	1.31±0.13$_a$	1.15±0.12$_{ab}$	2.30±0.22$_a$	1.34±0.11$_{ab}$	1.24±0.05$_{ab}$
D$_5$-15-Ser	1.35±0.10$_b$	0.99±0.06$_{ab}$	1.29±0.11$_{ab}$	1.32±0.10$_a$	1.10±0.09$_{ab}$	2.19±0.11$_b$	1.27±0.14$_{ab}$	1.13±0.19$_{ab}$
D$_5$-25-Jhabola	1.55±0.16$_a$	0.78±0.05$_b$	1.36±0.05$_a$	1.13±0.07$_{ab}$	1.23±0.09$_a$	1.87±0.11$_{ab}$	1.43±0.05$_a$	1.00±0.17$_b$
D$_6$-20-Seru Salasi	1.42±0.04$_{ab}$	0.99±0.18$_{ab}$	1.31±0.13$_{ab}$	1.31±0.09$_a$	1.15±0.16$_{ab}$	2.15±0.14$_b$	1.30±0.11$_{ab}$	1.15±0.05$_{ab}$
D$_6$-21-Malari	1.59±0.05$_a$	0.94±0.07$_{ab}$	1.19±0.14$_{ab}$	1.08±0.05$_b$	1.14±0.12$_{ab}$	1.98±0.08$_{ab}$	1.35±0.09$_{ab}$	1.07±0.17$_b$
D$_6$-23-Gujrera	1.42±0.15$_{ab}$	0.94±0.03$_{ab}$	1.30±0.19$_{ab}$	1.28±0.12$_{ab}$	1.19±0.20$_{ab}$	2.05±0.12$_b$	1.27±0.03$_b$	1.07±0.19$_b$
D$_7$-16-Dhroti	1.61±0.09$_a$	0.90±0.08$_{ab}$	1.14±0.06$_{ab}$	1.09±0.10$_b$	1.13±0.04$_{ab}$	1.85±0.06$_{ab}$	1.26±0.03$_{ab}$	1.09±0.15$_b$
D$_7$-17-Singaswin	1.62±0.06$_a$	0.83±0.08$_b$	1.18±0.10$_{ab}$	1.06±0.11$_b$	1.16±0.10$_{ab}$	2.02±0.15$_b$	1.22±0.10$_{bc}$	1.08±0.17$_b$
Mean	1.43±0.20	0.95±0.13	1.22±0.18	1.30±0.21	1.13±0.17	2.14±0.25	1.29±0.17	1.21±0.21

Values followed by a different lowercase letter within system are significantly different ($p<0.05$)

record higher SOC (62.81±9.80), whereas Kharli site had higher SOC (97.41±10.09) in forest soils. Grasslands of Tehri site record high SOC (63.89±9.93) as compared to other study sites. Soil organic carbon under different land use systems varied significantly (R^2=0.76, P<0.0001). Significantly higher SOC was recorded from forest soils, whereas SOC from agroforests and grasslands was statistically at par (Fig. 2).

The high SOC under forest and tree based systems is associated with more organic matter addition and their lower rate of decomposition (Singh *et al.,* 2000; Yadav *et al.,* 2008; Mandal *et al.* 2010; Koul and Panwar, 2012; Devi *et al*., 2013). Venkanna *et al.* (2014) reported higher SOC for forest (87.29 t ha^{-1}) as compared to cropping systems (36.86-60.03 t ha^{-1}). Soil erosion and other degradation processes might deplete SOC as reported by Dahal and Bajracharya (2010) for agriculture converted from forest ecosystem. Diversified organic matter produced by native species in forest ecosystem made better conditions for microbial community establishment and C cycling (Bini *et al.,* 2013). In case of grasslands, fibrous root system of plants and no-till condition also increases the organic carbon stocks of these soils (IPCC, 2000; Uri, 2001; Mandal *et al.,* 2005).

Principal Components Analysis (PCA)

In order to obtain a better understanding of the factors most directly related to the behaviour of the different land uses studied from 25 sites, PCA was used to examine the data. The PCA was carried out with 8 selected variables (Soil pH, EC, BD, OC, SOC and per cent values of sand, silt and clay) identified two components (PC1 and PC2) with eigenvalue > 2.0, that accounted for 62.9% of the total variance (Table 5). First component (PC1) was mainly associated with forest land use. PC1 accounted for 36.6% variance (Fig. 3) and highest positive loadings were found with OC (%) followed by SOC (t ha^{-1}) and sand (%). This is most important component for describing

Table 5
Principal components analysis Loading matrix

Variables	PC1	Pc2
Eigenvalue	2.93	2.10
pH	-0.60945	0.38090
EC (dS m^{-1})	-0.54354	0.43903
BD (g cc^{-1})	-0.50140	-0.56212
OC (%)	0.85973	0.40109
SOC (t ha^{-1})	0.80593	0.13405
Clay (%)	-0.62350	0.31923
Silt (%)	0.30315	0.74968
Sand (%)	0.37550	-0.77807

Table: 4
Soil organic carbon (t ha^{-1}) under different land use systems of study sites (values represent mean ± SD)

Site Number-Name	Land use systems			
	Agriculture	Agroforests	Forest	Grasslands
D$_1$-2-Jai Shri Devi	44.62±5.98$_a$	55.02±5.60$_a$	75.39±7.22$_a$	56.91±3.26$_a$
D$_1$-3-Badgaon	47.85±7.25$_a$	62.31±11.52$_a$	81.83±1.10$_a$	62.58±5.21$_a$
D$_1$-5-Jaddu	45.81±1.82$_a$	54.66±7.89$_a$	77.82±7.24$_a$	56.14±6.18$_a$
D$_1$-6-Malroan	49.15±8.50$_a$	56.74±13.17$_a$	80.90±15.81$_a$	54.77±1.54$_a$
D$_1$-13-Dhanola	46.74±4.85$_a$	57.37±3.98$_a$	77.37±9.92$_a$	59.79±7.60$_a$
D$_1$-19-Fugogh	47.24±3.78$_a$	56.70±5.42$_a$	79.16±10.89$_a$	61.28±6.00$_a$
D$_2$-7-Tihri	48.49±1.09$_a$	59.21±5.89$_a$	94.06±10.64$_a$	63.89±9.93$_a$
D$_2$-8-Jhunjnu	49.57±3.96$_a$	56.81±4.09$_a$	88.87±4.40$_a$	58.71±7.96$_a$
D$_2$-9-Paploh	49.41±1.36$_a$	55.55±6.22$_a$	89.17±9.27$_a$	56.46±9.12$_a$
D$_2$-10-Silwin	44.53±9.30$_a$	56.10±1.11$_a$	81.03±10.40$_a$	55.99±6.83$_a$
D$_2$-11-Kukrehar	48.08±4.81$_a$	55.57±7.70$_a$	83.02±9.44$_a$	58.33±10.86$_a$
D$_2$-12-Kharli	47.15±1.10$_a$	55.95±10.75$_a$	97.41±10.09$_a$	58.28±6.79$_a$
D$_3$-1-Jol	52.63±5.78$_a$	59.20±11.18$_a$	94.70±5.44$_a$	56.36±8.61$_a$
D$_3$-4-Gangloh	50.49±1.64$_a$	54.92±8.19$_a$	97.84±7.82$_a$	54.71±7.28$_a$
D$_3$-18-Raily	48.04±11.44$_a$	62.81±9.80$_a$	86.98±13.41$_a$	52.51±4.34$_a$
D$_4$-14-Beharan	45.80±4.06$_a$	53.64±0.97$_a$	81.47±11.90$_a$	51.31±4.34$_a$
D$_4$-22-Kuthera	48.33±6.79$_a$	60.32±3.00$_a$	86.74±10.15$_a$	51.36±9.95$_a$
D$_4$-24-Talai	51.41±8.21$_a$	60.55±8.10$_a$	94.82±11.84$_a$	59.37±4.48$_a$
D$_5$-15-Ser	47.96±5.06$_a$	61.43±7.40$_a$	86.29±10.98$_a$	52.12±13.4$_{4\,a}$
D$_5$-25-Jhabola	43.51±6.73$_a$	54.85±1.45$_a$	82.46±7.70$_a$	51.71±10.01$_a$
D$_6$-20-Seru Salasi	50.49±9.96$_a$	61.17±4.35$_a$	88.70±9.68$_a$	53.86±6.67$_a$
D$_6$-21-Malari	53.79±4.73$_a$	45.80±3.60$_a$	80.97±11.27$_a$	52.40±11.27$_a$
D$_6$-23-Gujrera	47.79±5.70$_a$	59.80±11.98$_a$	86.95±14.54$_a$	48.98±8.86$_a$
D$_7$-16-Dhroti	52.19±7.25$_a$	44.54±6.13$_a$	75.16±3.59$_a$	49.26±5.68$_a$
D$_7$-17-Singaswin	48.22±6.32$_a$	45.10±8.87$_a$	84.40±13.04$_a$	46.91±4.92$_a$
Mean	48.37±5.65	56.25±7.88	85.34±10.57	55.24±7.63

Values followed by a different lowercase letter within system are significantly different ($p<0.05$)

the distribution of different land use systems of selected study sites. PC2 was mainly associated with agriculture land use system. Contribution from second component (PC2) to the total variance was 26.3% (Fig. 3) and highest positive loading was found with silt (%) followed by EC, pH and clay content (%), whereas negative higher loading was found with bulk density (BD).

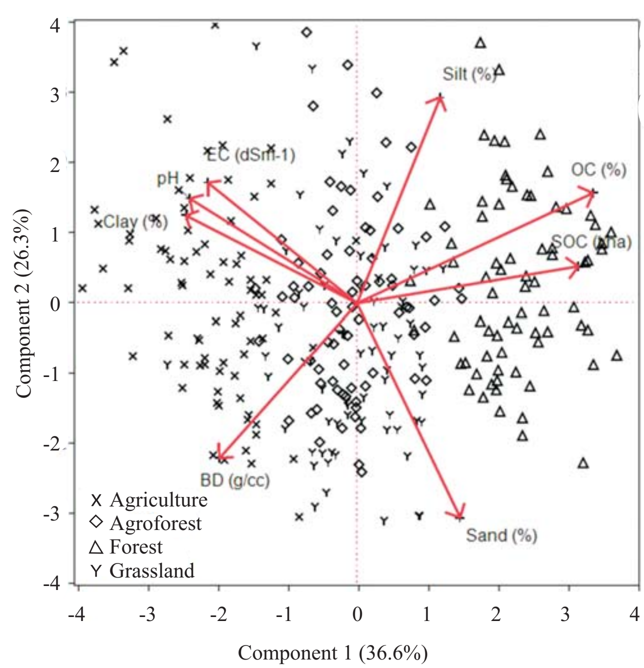


Fig. 3. Principal component (PCA) ordination diagram for first two axes showing the landscape partitioning of different land use systems of 25 study sites in relation to soil physico-chemical properties

4. CONCLUSIONS

This study indicates that the sites located near reservoir in upstream catchment area had high soil pH, EC, SOC and low bulk density. Type of plant from different land use systems made trocs in litter addition and storage of SOC. Forest soils exhibited higher organic matter and conserved high SOC. It was revealed that the soil pH, EC and compactness of soil decreased with increase in SOC under forests. Organic carbon (%) is the most important component for describing the allocation of diffèrent land use systems. It helps to develop conservation plan in upstream catchment area.

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