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Soil quality under forest compared to other land-uses in acid soil of north western Himalaya, India

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Abstract. Present research was undertaken to examine the impact of land use on soil fertility in an Alfisol, at Dharamshala district of north western Himalayan region, India. Soil samples were collected from 0-15, 15–30, 30–45 and 45-60 cm soil depths of five landuses viz. natural forest of *Pinus roxburghii*, grassland, horticulture, agriculture and wasteland. Soil was examined for pH, organic carbon (OC), electrical conductivity (EC), cation exchange capacity (CEC), available nitrogen (N), phosphorus (P), exchangeable calcium (Ca), magnesium (Mg), potassium (K), aluminium (Al), microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), microbial biomass phosphorus (MBP), acid phosphatase activity (APHA) and dehydrogenase activity (DHA). Soil pH varied from 5.22 in forest and 5.72 in grassland. OC content was higher in forest (3.01%), followed by grassland (2.16%) and was least (0.36%) in deeper layers of agriculture. Highest N content was found under forest (699, 654, 623 and 597 kg/ha, at 0-15, 15-30, 30-45 and 45-60 cm depth, respectively), followed by grassland, horticulture and agriculture and least in wasteland. Maximum exchangeable Ca and Mg were found in grassland (0.801 c mol kg^{-1} and 0.402 c mol kg^{-1}, respectively). Exchangeable K and Al were higher under forest (0.231 c mol kg^{-1} and 1.89 c mol kg^{-1}, respectively) least in wasteland. Soil biological properties were highest under surface soil of forest (576 mg kg^{-1}, 31.24 mg kg^{-1}, 6.55 mg kg^{-1}, 29.6 mg PNP $g^{-1}h^{-1}$ and 35.65 µg TPF 24 h^{-1} g^{-1} dry soil, respectively for MBC, MBN, MBP, APHA and DHA) and least in 45-60 cm layer, under wasteland. The forest had a higher fertility index and soil evaluation factor followed by grassland, horticulture, agriculture as compared to wasteland.
Keywords soil fertility index, soil evaluation factor, available nutrients, exchangeable cations, landuse, microbial activity.

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Introduction

In the last decades, severe changes in land use occurred in tropical countries, due to increasing population and their demand for food resources (Lambin et al. 2001). Forest land is rapidly converted into agriculture or pastureland, which may cause significant changes in soil fertility. Landuse exerts significant effect on nutrient availability and may also influence secondary succession and biomass production (Lu et al. 2002). Nutrient cycling in agroforestry is in between natural forest ecosystems of the tropics and most of the agricultural systems with are ''leaky'' having higher nutrient losses (Nair et al. 1995).

Soil quality indicators are categorised into physical, chemical, and biological indicators which helps in monitoring changes in soil quality by assessing changes in these indicators (Doran & Parkin 1994). Soil quality/fertility index is computed by converting them into single value. It is imperative to compare the changes in soil health caused by land use changes affecting natural resources and ecology (Abbasi et al. 2010).

Research indicated that decline of soil organic matter may occur due to conversion of forest and grassland into agriculture (Ouattara et al, 2006). Tree growth is highly influenced by base cations (Ca, Mg, K, Na) concentration, cation exchange capacity , and concentrations of Al and Mn (Adams et al. 2000). Calcium and N are specifically important, as they are primary constituents of biomass and regulates cell function of many tree species (Bigelow & Canham 2007). Base cations also help in alleviating the effects of Al toxicity in acid soil (Juice et al. 2006).

Soil microbial biomass is important source and sink of nutrients (Singh et al. 1989). This is an important labile pools of C and nutrients (Wardle 1992) from which nutrients are released after the microorganism dies. Soil microorganisms respond very quickly to various natural and anthropogenic pressures or stresses acting on the soil ecosystem.

It was hypothesized that land uses affects soil properties, as compared to wasteland which was taken as control. With this background, the present study was undertaken with the objectives to (i) compare influence of five most common land–use on selected soil chemical and biological properties in north-west Himalayan zone and (ii) establish the inter-relationship between soil fertility indices, soil evaluation factor, microbial indices and soil properties.

Materials and methods

Soil sampling, processing and analysis of soil properties

The field is located in Dharmshala District of Himachal Pradesh State, India. The experiment site is situated at 30°6'0" N and 73°3'0" E longitude, 1300 m elevation. The mean annual temperature ranges from 15-19° C and the rainfall is 2500 to 3000 mm. According to the USDA Soil Taxonomy the soil is classified as Typic Hapludalf. The pH ranges from 5.3 to 5.8. Landuse systems studied were (i) natural forest of *Pinus roxburghii* (ii) grassland (iii) mango plantation (Horticulture) (iv) agriculture (monocropping of Paddy/wheat/maize) (v) wasteland.

Collection of soil sample was done from four layers: 0–15 cm, 15–30 cm, 30-45 cm and 45-60 cm, in three replications. Soil samples were passed through a 2-mm sieve after air drying. A combined glass–calomel electrode was used to determine the pH of aqueous suspensions (1:2.5 soil:solution ratio). Electrical conductivity (dS m-1) was measured by conductivity bridge (Richards, 1954) in 1:2 soil water suspension. Soil organic carbon (OC) was determined by wet digestion method (Walkley & Black 1934). Available nitrogen (N) and phosphorus were measured by the alkaline permanganate method (Subbiah & Asija 1956) and Bray II method (Bray & Kurtz 1945), respectively. Cation exchange capacity (CEC) was calculated following method of Jackson (1974). 1M NH4OAc (pH 7.0) was used to extract exchangeable Ca, K and Mg. Potassium content was determined by flame photometer (Rich 1965), while EDTA titration was done to measure Ca and Mg. Exchangeable Al was extracted with 1N KCl solution and titrated with 0.1N NaOH. Available micronutrient content (Cu, Mn, Fe and Zn) were estimated using by DTPA extraction procedure(Lindsay & Norvell 1978), followed by determination in atomic absorption spectrophotometer.

Soil biological properties

Microbial biomass carbon (MBC) determinations were made by using chloroform fumigation technique, as described by Jenkinson & Powlson (1976) and Jenkinson & Ladd (1981). Microbial biomass nitrogen (MBN), MBP and APHA were determined was by using standard methods (Brookes et al. 1985, Brookes et al. 1982, Tabatabai & Bremner 1969). The dehydrogenase activity (DHA) was calculated through tri-phenyl tetrazolium chloride (Tabatabai 1982) procedure.

Computation of indices

Values of soil fertility index (*SFI*) (Moran et al. 2000) and soil evaluation factor (*SEF*) (Lu et al. 2002) were calculated to quantify soil fertility. Soil fertility index was computed by the equation as follows (Lu et al. 2002):

$$SFI = pH + organic\ matter_{[\%,\ dry\ soil\ basis]} + available\ P_{[mg\ kg\text{-}1,\ dry\ soil]} + exch.\ K_{[c\ eq\ kg\text{-}1,\ dry\ soil]} + exch.\ Ca_{[c\ eq\ kg\text{-}1,\ dry\ soil]} + exch.\ Mg_{[c\ eq\ kg\text{-}1,\ dry\ soil]} - exch.\ Al_{[c\ eq\ kg\text{-}1,\ dry\ soil]}$$

$$SEF = [exch.\ K_{[c\ eq\ kg\text{-}1,\ dry\ soil]} + exch.\ Ca_{[c\ eq\ kg\text{-}1,\ dry\ soil]} + exch.\ Mg_{[c\ eq\ kg\text{-}1,\ dry\ soil]} - log(1 + exch.\ Al_{[c\ eq\ kg\text{-}1,\ dry\ soil]})] \cdot organic\ matter_{[\%,\ dry\ soil]} + 5$$

Statistical analysis

Research data was analysed by ANOVA appropriate to the experimental design. Microsoft Excel and MSTATC packages were used for statistical analysis The relationship between soil properties and soil fertility indices were determined by Pearson's correlation matrix using SPSS window version 14.0 (SPSS Inc., Chicago, USA).

Results

Effect of land–use systems and on soil depths. Soil properties under different land uses are given in Table 1. Significant effect of landuse on soil pH was found (5.22 in forest and 5.72 in grassland), however, variation in soil pH with respect to depth was non-significant.

OC content was higher in surface layer of forest land–use (3.01%), followed by grassland (2.16%) and least in deeper soil layers of agriculture (0.36%). As a general trend, OC decreased with the increase in the depth of soil.

Cation exchange capacity did not vary significantly with depth. It was higher in grassland (15.81 c mol kg^{-1}), followed by forest (15.20 c mol kg^{-1}) and least in wasteland (13.01 c mol kg^{-}). Johnson (2002) also found high CEC in forest soils with high OC content.

Effect of land–use and soil depth on avaiable nitrogen, phosphorus and potassium in soil. Highest N content was found under forest (699, 654, 623 and 597 kg/ha, at 0-15, 15-30, 30-45 and 45-60 cm depth, respectively), followed by grassland, horticulture and agriculture and least under wasteland. Nitrogen content decreased significantly with soil depth. A similar trend was found in the case of available phosphorus and potassium also, although the depth effect was non significant (Table 2).

Effect of land–use and soil depth on

echangeable nutrient cations. Exchangeable nutrient cations were significantly influenced by land use (Table 3). Exchangeable Ca was highest (0.801 c mol kg^{-1}) in grassland at 0-15 cm depth and least in wasteland (0.602 c mol kg^{-1}) at 45–60 cm depth. The Mg content was highest (0.402 c mol kg^{-1}) in grassland at 15-30 cm and least (0.201 c mol kg^{-1}) in horticulture at 45-60 cm soil layer. Exchangeable K varied from 0.231 c mol kg^{-1} in forest to 0.081 c mol kg^{-1} in wasteland. Exchangeable Al varied from 1.89 c mol kg^{-1} in surface soil of forest to 1.23 c mol kg^{-1} in horticulture at 45-60 cm depth. Similar results had been reported for Ca, Mg and Na, by Sharma et al. (2009).

Effect of land–use and soil depth on available micronutrients. The content of Cu was highest (2.98 ppm) in forest and lowest (0.45 ppm) in wasteland. Zinc content varied from 1.92 ppm in surface soil of forest and least (0.98 ppm) in wasteland. Manganese content was greatest (4.52 ppm) in 0-15 cm soil depth of forest and least (1.09 ppm) in 30-45 cm soil depth of wasteland. Available Fe varied from 8.11 ppm in surface soil of forest to 4.21 ppm in 30-45 cm depth in agriculture (Figure 1a, 1b, 1c, 1d). All the micronutrients did not show any consistent trend both for land–use as

Table 1 Effect of land–use systems on chemical properties of soil

System	Soil layer (cm)			
	0-15	15-30	30-45	45-60
pH				
Forest	5.22	5.30	5.34	5.21
Grassland	5.69	5.70	5.61	5.72
Horticulture	5.46	5.56	5.50	5.59
Agriculture	5.50	5.49	5.53	5.53
Wasteland	5.60	5.69	5.65	5.64
$LSD_{0.05}$	L = 0.12	D = NS	L × D = NS	
Organic carbon (%)				
Forest	3.01	2.29	1.86	1.25
Grassland	2.16	1.85	1.69	1.17
Horticulture	1.68	1.52	1.04	1.23
Agriculture	0.90	0.65	0.49	0.36
Wasteland	0.85	0.56	0.50	0.45
$LSD_{0.05}$	L = 0.045	D = 0.006	L × D = 0.031	
Electrical conductivity (dS m^{-1})				
Forest	0.24	0.26	0.24	0.26
Grassland	0.25	0.25	0.25	0.24
Horticulture	0.25	0.23	0.22	0.26
Agriculture	0.22	0.22	0.25	0.25
Wasteland	0.23	0.22	0.25	0.26
$LSD_{0.05}$	L = NS	D = NS	L × D = NS	
Cation exchange capacity (c mol kg^{-1})				
Forest	15.20	15.01	14.42	15.12
Grassland	15.81	15.01	15.00	14.96
Horticulture	14.90	14.65	13.98	14.21
Agriculture	14.30	13.65	14.35	13.87
Wasteland	13.80	13.23	13.01	14.20
$LSD_{0.05}$	L = 0.25	D = NS	L × D = NS	

Note. L - Landuse system, D - Soil layer, NS - Non significant. LSD, least significant difference at the 5% probability level.

well as for soil layer.

Effect of land–use and soil depth on soil biological properties. The soil biological properties (Table 4) like MBC, MBN, MBP, APHA and DHA was highest under surface soil of forest (576 mg kg^{-1}, 31.24 mg kg^{-1}, 6.55 mg kg^{-1}, 29.6 mg PNP $g^{-1}h^{-1}$ and 35.65 µg TPF 24 h^{-1} g^{-1}dry soil, respectively) and least in 45-60 cm layer under wasteland (198 mg kg^{-1}, 8.98 mg kg^{-1}, 2.21mg kg^{-1}, 15.46 mg PNP $g^{-1}h^{-1}$ and 18.6 µg TPF 24 h^{-1} g^{-1} dry soil, respectively).

Soil fertility index and soil evaluation factor under different land–use systems at varying depths

There was a decrease in fertility index in all land-use, from surface layer to deepest layer (Figure 2a). Forest showed a higher average fertility index, followed by grassland, horticulture, agriculture as compared to wasteland (Figure 2b). The higher fertility in surface soil in forest is attributed to the highest accumulation of organic matter due to litter fall. With increasing soil depth, SEF declined in all land uses (Figure 3 a and b). The trend in all the land-use for all the soil depth was similar forest >grassland>horticulture>agriculture> wasteland. (Figure 3 a). Averaging the soil layer of each land–use (3 b), it was found that SEF was more (7.97) for forest followed by grassland (7.83), horticulture (6.83), agriculture (5.87) and least in wasteland (5.79).

Correlations between soil properties and soil fertility indices

Pearson's correlation matrix (Table 5) revealed strong significant positive correlation of SFI

Table 2 Effect of land–use systems on available nutrients in soil profile

System	Soil layer (cm)			
	0-15	15-30	30-45	45-60
Available nitrogen (kg ha^{-1})				
Forest	699	654	623	597
Grassland	426	401	395	352
Horticulture	401	357	346	321
Agriculture	301	295	258	278
Wasteland	286	249	271	250
$LSD_{0.05}$	L = 16.25	D = 7.21	L × D = 12.43	
Available phosphorus (kg ha^{-1})				
Forest	17.23	16.44	16.21	15.01
Grassland	15.47	14	13.91	13
Horticulture	13.24	12.9	14.23	13.21
Agriculture	12.31	12	11.96	10.90
Wasteland	11.48	10.21	11.12	12.13
$LSD_{0.05}$	L = 0.21	D = NS	L × D = NS	
Available potassium (kg ha^{-1})				
Forest	301.61	295.4	290.1	287.3
Grassland	285.21	273.1	282.72	267.5
Horticulture	271.5	267	254	265
Agriculture	265	278	264	276
Wasteland	264	278	254	267
$LSD_{0.05}$	L = 13.25	D = NS	L × D = NS	

Note. L - Landuse system, D - Soil layer, NS - Non significant. LSD, least significant difference at the 5% probability level.

Table 3 Effect of land–use systems on exchangeable nutrients in soil profile

System	Soil layer (cm)			
	0-15	15-30	30-45	45-60
Exchangeable Ca (c mol kg^{-1})				
Forest	0.786	0.689	0.635	0.701
Grassland	0.801	0.752	0.804	0.687
Horticulture	0.710	0.717	0.621	0.604
Agriculture	0.657	0.602	0.683	0.599
Wasteland	0.623	0.711	0.605	0.602
$LSD_{0.05}$	L = 0.003	D = 0.001	L × D = NS	
Exchangeable Mg (c mol kg^{-1})				
Forest	0.256	0.247	0.234	0.203
Grassland	0.402	0.398	0.305	0.297
Horticulture	0.235	0.249	0.203	0.201
Agriculture	0.367	0.355	0.364	0.321
Wasteland	0.301	0.287	0.267	0.254
$LSD_{0.05}$	L = 0.001	D = 0.002	L × D = 0.004	
Exchangeable K (c mol kg^{-1})				
Forest	0.231	0.224	0.209	0.212
Grassland	0.191	0.189	0.187	0.190
Horticulture	0.142	0.135	0.140	0.141
Agriculture	0.128	0.125	0.107	0.102
Wasteland	0.081	0.125	0.097	0.101
$LSD_{0.05}$	L = 0.041	D = NS	L × D = NS	
Exchangeable Al (c mol kg^{-1})				
Forest	1.89	1.78	1.80	1.78
Grassland	1.58	1.49	1.51	1.52
Horticulture	1.50	1.48	1.51	1.23
Agriculture	1.75	1.62	1.70	1.61
Wasteland	1.56	1.62	1.57	1.62
$LSD_{0.05}$	L = 0.02	D = NS	L × D = NS	

Note. L - Landuse system, D - Soil layer, NS - Non significant. LSD, least significant difference at the 5% probability level.

and SEF with OC, CEC, N, P, K, MBC, MBN, MBP, APHA and DHA. Among the soil fertility parameters like available K, P, N and biological parameters like MBC, MBN and DHA showed strong positive relationship with OC. With increase in CEC of the soil, microbial activity increased significantly, as evidenced from very high positive values of correlation coefficients.

Discussion

Effect of land–use systems on soil fertility and chemical properties at different depths. Decomposition of soil organic matter releases organic acids leading to decrease in pH in forest (Killham 1994). Poor quality of irrigation water may be the reason for increase in soil pH in agriculture site (Minhas et al, 2007). EC did not vary significantly under different land–uses at varying soil depths. Although, the higher values of EC under tree–based land–use system, as com-

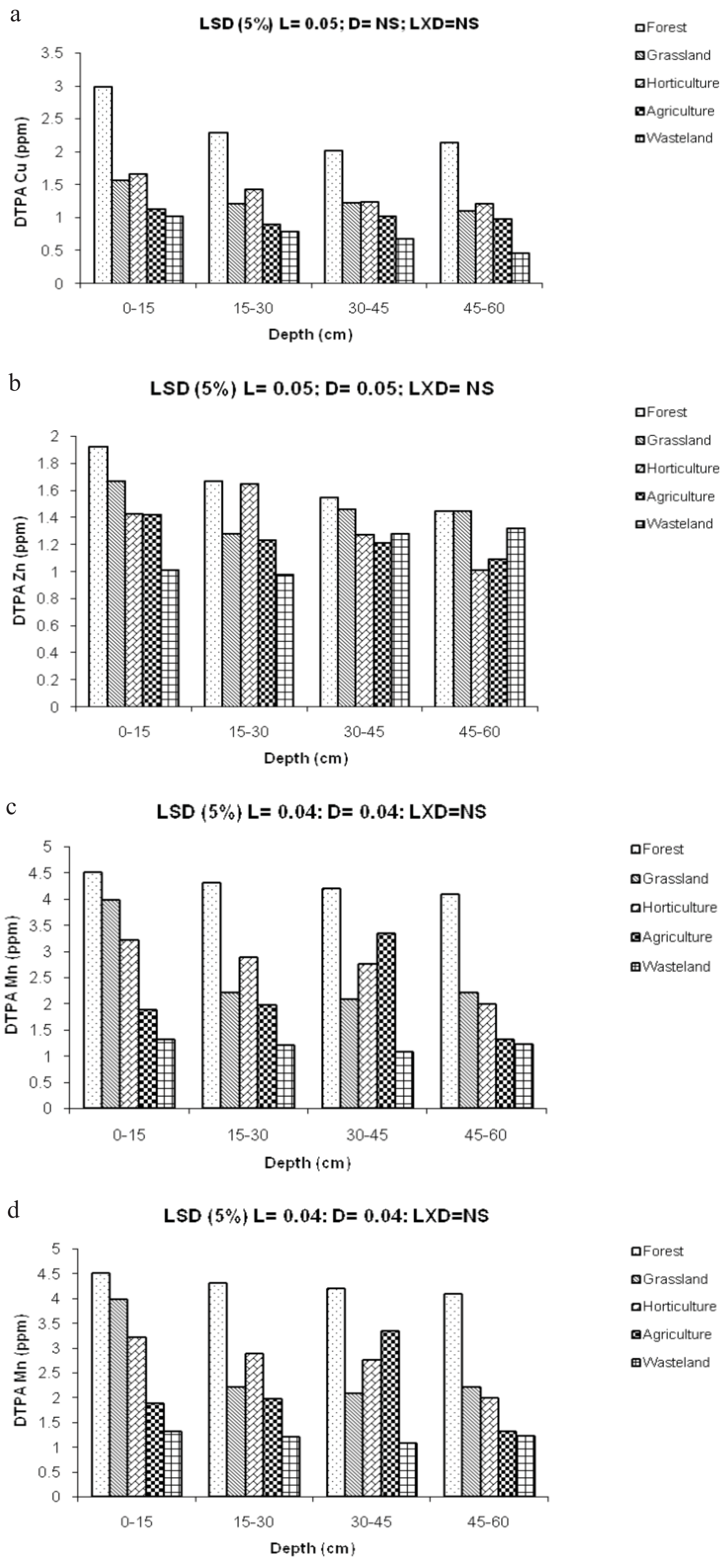

Figure 1 Effect of different land–use systems on DTPA extractable micronutrients in soil profile (a) Cu, (b) Zn, (c) Mn and (Fe)(d)

Table 4 Effect of land–use systems on soil biological properties

System	Soil layer (cm)			
	0-15	15-30	30-45	45-60
Microbial biomass carbon (mg kg^{-1})				
Forest	576	535	501	497
Grassland	487	401	376	324
Horticulture	435	398	302	298
Agriculture	324	301	301	225
Wasteland	265	225	278	198
$LSD_{0.05}$	L = 21.03	D = 15.5	L × D = 17.54	
Microbial biomass nitrogen (mg kg^{-1})				
Forest	31.24	28.97	23.76	25.54
Grassland	28.76	23.34	21.56	19.01
Horticulture	30.01	18.96	18.65	15.45
Agriculture	24.34	19.78	14.56	10.05
Wasteland	20.98	16.99	15.34	8.98
$LSD_{0.05}$	L = 1.65	D = 2.01	L × D = NS	
Microbial biomass phosphorus (mg kg^{-1})				
Forest	6.55	4.08	4.27	4.01
Grassland	5.24	4.00	3.01	2.99
Horticulture	4.87	3.79	2.98	3.21
Agriculture	3.21	3.02	2.87	2.21
Wasteland	2.65	2.54	2.41	2.21
$LSD_{0.05}$	L = 0.056	D = NS	L × D = NS	
Acid phosphatase (mg PNP g^{-1} h^{-1})				
Forest	29.60	26.50	23.05	23.00
Grassland	25.20	21.30	19.01	17.89
Horticulture	23.65	19.68	18.78	17.05
Agriculture	21.98	20.67	17.01	15.78
Wasteland	19.07	18.76	16.90	15.46
$LSD_{0.05}$	L = 2.35	D = NS	L × D = NS	
Dehydrogenase activity (μg TPF 24 h^{-1} g^{-1}dry soil)				
Forest	35.65	30.98	29.76	28.65
Grassland	27.54	25.62	24.78	25.03
Horticulture	23.34	22.10	20.90	19.98
Agriculture	22.45	22.00	18.79	17.86
Wasteland	19.56	20.60	20.80	18.60
$LSD_{0.05}$	L = 5.43	D = 2.35	L × D = NS	

Note. L - Landuse system, D - Soil layer, NS - Non significant. LSD, least significant difference at the 5% probability level.

pared to arable land, has been reported earlier by Sharma & Gupta (1989). Silt, clay, residue turnover from biomass and its decomposition rate are the critical factors in SOC build up in soil (Park & Matzner 2003). Naitham & Bhattacharyya (2004) had also reported that soils under horticulture and forest had higher SOC than agriculture. Lesser carbon input in through residue in reference site low SOC. Trees had long been found to increase OC, extractable P, and exchangeable cations (Tomlinson et al. 1995). The inconsistency of micronutrients,

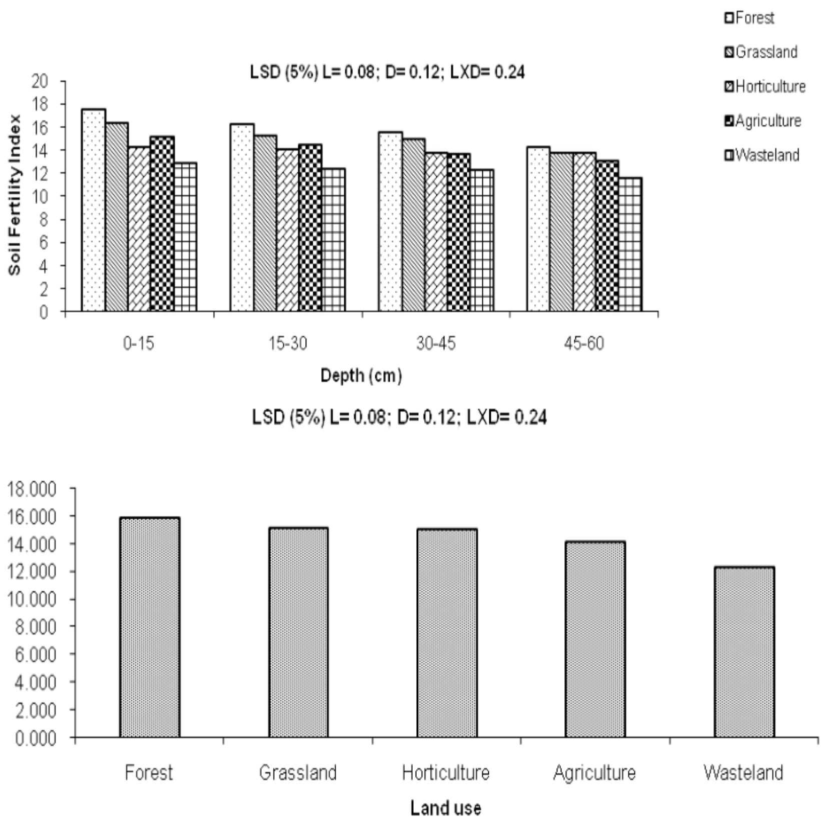

Figure 2 Effect of different land–use systems and depths on (a) soil fertility index with depths, (b) soil fertility with land–use

particularly Cu and Zn, with respect to soil depth had also been reported by Sharma et al. (2009).

Effect of land-use and soil depth on soil biological properties. The values of MBC obtained in present research falls within reported range (61̄1900 mg kg-1) (Srivastava & Singh 1988). Soil organic matter content and enzyme activities are strongly related to each others (Gracia et al. 1994). The decline of microbial biomass in lower layers is attributed to lesser availability of SOC (Franzleubber et al. 1994).

Conclusions

It is evident from the study that forest based landuse increased OC, exchangeable cations, available nutrients and microbial activities. The trees to be used should be deep rooted, as they are capable of utilizing nutrients which are present beyond the root zone of agriculture crops, and also help in nutrient cycling. A balanced tree–crop combination is ideal for both production and maintaining the soil health. A highly significant correlation of SFI and SEF with soil chemical and biological properties indicates that these two indices can successfully be used as indicators of soil quality.

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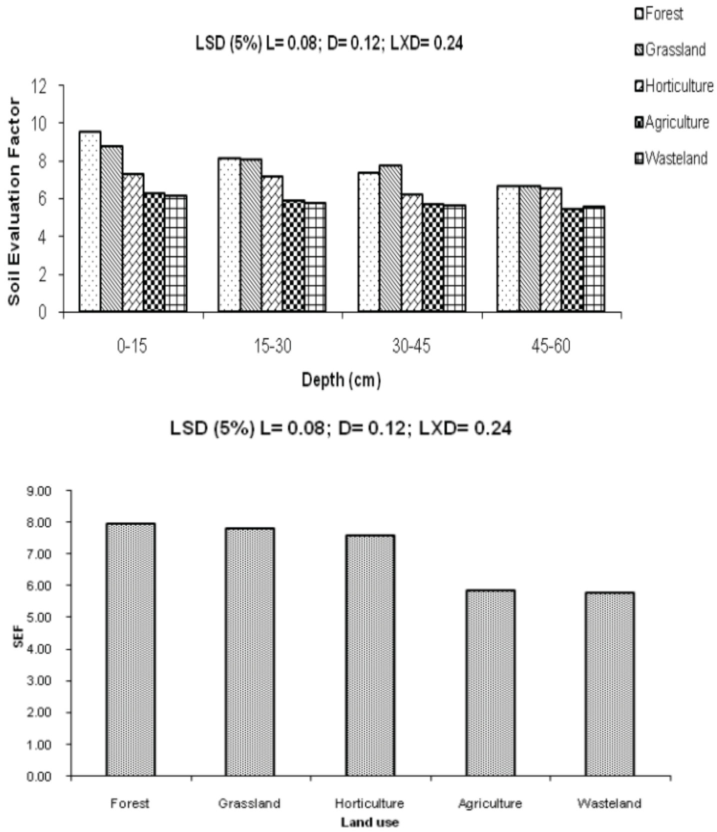

Figure 3 Effect of different land–use systems and depths on (a) soil evaluation factor with depths and (b) soil evaluation factor with land–use

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Table 5 Correlation between soil properties and soil fertility indices

Variable	pH	OC	EC	CEC	AN	AP	AK	Ca	ExK	ExAl	MBC	MBN	MBP	APHA	DHA	SFI	SEF
pH	1.00	NS	NS	NS	-0.775**	-0.619**	-0.597**	NS	-0.496*	-0.671**	-0.655**	-0.505*	-0.527**	-0.636**	-0.617**	-0.509*	NS
OC		1.00	NS	NS	NS	0.895**	0.698**	0.697**	0.847**	NS	0.907**	0.829**	0.905**	0.860**	0.889**	0.883**	0.983**
EC			1.00	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CEC				1.00	0.623**	0.752**	0.551**	0.735**	0.759**	NS	0.756**	0.655**	0.747**	0.621**	0.669**	0.721**	0.802**
AN					1.000	0.920**	0.811**	0.436*	0.889**	0.564**	0.930**	0.746**	0.780**	0.838**	0.945**	0.779**	0.769**
AP						1.000	0.687**	NS	0.893**	NS	0.911**	0.732**	0.816**	0.8**	0.896**	0.841**	0.846**
AK							1.000	0.530**	0.770**	0.598**	0.742**	0.605**	0.677**	0.755**	0.819**	0.713**	0.689**
Ca								1.000	0.625**	0.500*	0.612**	0.629**	0.654**	0.575**	0.592**	0.622**	0.784**
Mg									NS	NS	NS	NS	NS	NS	NS	NS	NS
ExK									1.000	NS	0.872**	0.715**	0.737**	0.748**	0.927**	0.805**	0.821**
ExAl										1.000	NS	NS	NS	0.556**	0.564**	NS	NS
MBC											1.000	0.872**	0.892**	0.903**	0.929**	0.873**	0.871**
MBN												1.000	0.852**	0.938**	0.816**	0.829**	0.816**
MBP													1.000	0.907**	0.833**	0.855**	0.896**
APHA														1.000	0.893**	0.879**	0.840**
DHA															1.000	0.852**	0.858**
Cu																0.817**	0.790**
Mn																0.782**	0.716**
Fe																0.760**	0.903**
ZN																0.754**	0.786**
SFI																1.000	0.887**
SEF																	1.000

Note. ** - significant $p < 0.01$, * - significant $p < 0.05$.

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