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Assessment of soil biochemical properties and soil quality index under rainfed land use systems in submontane Punjab, India

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The conversion of natural systems to cultivated systems contributes to changes in the activities of microbial communities and biochemical processes in the soil. A total of 80 surface soil samples (0-15 cm) from 6 rainfed land use systems *viz*. agriculture, horticulture, agri-horticulture, forest, agroforestry and eroded lands were analyzed for biochemical properties and to derive soil quality index. The soils are slightly acid to neutral in reaction (pH-6.4-6.9) with 0.09-0.23 dS m^{-1} electrical conductivity (EC), loamy sand to sandy loam in texture, 1.4-6.1 g kg^{-1} soil organic carbon (SOC), 86-406 kg ha^{-1} available nitrogen, 29.3-32.6 kg ha^{-1} available phosphorus,65-226 kg ha^{-1} available potassium,10.3-21.3 mg kg^{-1} DTPA-Mn, 12.1-34.2 mg kg^{-1} DTPA-Fe, 0.34-1.01 mg kg^{-1} DTPA-Cu and 0.76-1.15 mg kg^{-1} DTPA-Zn, respectively under different land use systems. Among soil biochemical properties, the enzymic activity among land use systemsis varied from 7.4 to 12.8 µg TPF g^{-1} h^{-1} for dehydrogenase activity, 22.3 to 34.5 µg pNP g^{-1} h^{-1} for acid phosphatase, 43.4 to 60.1 µg pNP g^{-1} h^{-1} for alkaline phosphatase, 3.31 to 4.77 µg NH$_4$-N g^{-1} soil min^{-1} for urease activity-, basal soil respiration −0.13 to 0.30 µg CO$_2$ g^{-1} soil h^{-1} for basal respiration , 46.5 to 242.6 µg g^{-1} soil for soil microbial biomass carbon (MBC) and 8.68 to 30.6 g kg^{-1} for total easily extractable glomalin (TEGP), respectively. The principle component analysis showed that SOC, EC, TEGP, MBC and DTPA-Zn are robust soil quality indicators under different land use systems in submontane Punjab. The forestry system has higher values for physicochemical, biochemical properties and soil quality index as against agri-horticulture, horticulture, agroforestry, agriculture and eroded system. In subsystems, eucalyptus-based forestry and mango based agri-horticulture systems are served as a better system for soil quality assessment in submontane Punjab, India.

Keywords: Dehydrogenase, Microbial biomass, Soil biochemical properties, Total glomalin

Environmental degradation due to inappropriate land use is a worldwide concern that has drawn attention to sustainable agricultural production systems. In rainfed areas, pastures and perennial land use systems are receiving great attention and exploitation without any due consideration of its consequences on soil quality, agricultural productivity, economic growth and healthy environment at global scale[1]. The changes in land use are important anthropogenic activities under natural ecosystems, affecting the below-ground ecosystem, plant cover, composition and biomass[2]. The extent of deterioration and degradation of soil quality can be examined through monitoring of soil physical, chemical and biochemical properties. It is generally accepted norm that soil physico-chemical parameters alter only when the soils undergo a drastic change whereas soil biological and biochemical parameters are sensitive to the slight modifications in rhizospheric soil[3]. The soil rhizosphere is highly influenced by the soil microbial activity and plant roots systems operating in nutrient availability of soils[4]. Soil management and cropping practices are commonly known to alter almost all soil biological processes as well as soil quality in agricultural systems. The changes in vegetation are also found to alter the soil organic reserve as well as soil microbial activities which modified the physicochemical characteristics of the soils[5]. The characterization of soil quality requires the selection of the most sensitive soil properties subjected to changes under a defined set of management practices and land-use systems. Soil organic matter, being an important indicator of soil quality is essential for soil enzymic activity and metabolic activity of soil microorganisms[6]. Soil enzymes are very sensitive to change in soil environment and help to understand the composition of organic carbon[7]. The integration of the soil properties into a more pragmatic and single index as soil quality index shall be helpful in assessing the soil quality. It has been observed that forest land use has

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highest SQI than other systems and soil organic carbon, potassium; EC, plant available water and clay content were key the indicators to affect the soil quality[8].

In India, rainfed area constitutes about 58 per cent of net cultivated area[9] and supports about 44 per cent of food production. In Punjab, about ten per cent of total geographical area is rainfed and known as sub montane Punjab. This region has multifaceted problems of poor soil fertility, erratic rainfall, low soil moisture and enlarged economic disparities within the state. The sub montane region of Punjab is the most fragile and degraded ecosystems in the country. The soil quality degradation is a major challenge in sub-montane Punjab and it is important for planners and decision makers to combat soil quality degradation through the introduction of appropriate interventions. To assess soil quality, it is necessary to select potential soil indicators for a specific area which have the capacity to perform a specified function in soil[10].

The information on soil quality is scanty in sub-montane region of Punjab, therefore, the present study was made with an objective to evaluate the most efficient soil quality indicators and assessed soil biochemical properties under different land use systems.

Materials and Methods

Experimental site

The study was conducted in submontane region of Punjab block, Talwara district, Hoshiarpur, India. It is located at 31°53′ N latitude and 75°92′ E longitude with an elevation of 296 m above mean sea level. The region is semiarid with bimodal rainfall pattern. The annual normal rainfall is 1051 mM, of which 80% receives from June to September and rest from November to March. The texture of soils in the region is loamy sand to sandy clay loam. The six prominent land use systems (agriculture, horticulture, agri-horticulture, forestry, agroforestry and eroded systems) were considered in the study. The agriculture systems further comprised of maize-wheat cropping system with more than 10 years. Horticulture systems included mango (*Mangifera indica*) and mandarin hybrid (mandarin hybrid) (*Citrus reticulata*) with more than 10 years old. Agri-horticulture system included mango-based systems with less than 6 years. The fodder during *kharif* season and oil seed during *rabi* season were grown as intercrop. Forest land use systems included populus (*Populus deltoides*), bamboo species and eucalyptus species more than 10 years old. Agroforestry systems included chinaberry (*Melia azedarach*) and eucalyptus species-based system with less than 6 years with fodder crop during *kharif* season and oil seed crops during *rabi* season as intercrop. The eroded (uncultivated) system included the barren lands.

Soil sampling

The study comprised of 6 main land use systems and 10 subland use systems. A total of 80 soil samples have been collected from 10 sub-land use systems with eight samples from each subland use system and georeferenced the sampling sites using global positioning system (GPS). Soil samples (0-15 cm) were collected after the harvest of *kharif* season. Soil samples from each plot were mixed sieved (2 mM) and divided into two halves. One-half of sample was immediately stored at 4ºC to assay soil biochemical activities and other half was air-dried and stored for physico-chemical analysis. The soil pH (1:2 *w/v*) was determined by using glass electrode[11] and electrical conductivity (EC) (1:2 *w/*v) by using conductivity bridge[11]. Soil texture was analyzed by International pipette method[12] and soil organic carbon by using wet combustion rapid titration method[13]. The available nitrogen in soil was analyzed by using alkaline permanganate method[14], available phosphorous in soil by using 0.5 M $NaHCO_3$ (pH 8.5) as extractant[15], available potassium in soil through flame photometer by using 1 N ammonium acetate (NH_4OAc) at pH 7 as extractant[16] and available micronutrient by using DTPA as extractant[17]. Among soil biochemical activities, dehydrogenase activity in soil was determined by mixing fresh soil with calcium carbonate and 1% TTC (2,3,5-triphenylterazolium chloride) solution. The mixture was incubated at 30C for 24 h in an incubator and slurry was transferred on Whatman filter paper No.1. The volume of the filtrate was made to 50 ml by adding methanol. The optical density of filtrate was read on Spectrophotometer at 485 nM using methanol extract as a blank[18]. The acid and alkaline phosphatase content was estimated as per the standard procedure[19]. The procedure described for estimation of phosphomonoestrase activities was based on colorimetric estimation of p-nitrophenol released by phosphate activities when soil was incubated with buffer (pH 6.5 for acid phosphate and pH 11.0 for alkaline phosphate) with disodium p-nitrophenyl phosphate solution. Urease activity was assayed by colorimetric method by treating the incubated soil samples with 2 M KC1 containing a urease inhibitor (phenylmercuric acetate) as per the procedure given by Douglas and Bremner[20]. Basal soil respiration was determined by estimating CO_2 adsorption in standard alkali (NaOH) in a given period and known volume[21]. Microbial biomass carbon (MBC) activity was determined by chloroform fumigation extraction method[22]. Soil samples were fumigated with $CHCl_3$ for 24 h at 20C. Fumigated and non-fumigated samples were extracted with 0.5 M K_2SO_4 (30 min at 200 rpm) and filtered by using 0.45 mM cellulose ester filter.

MBC = 2.22 (carbon fumigated soil extract - carbon unfumigated soil extract)

Glomalin content (total and easily extractable) as extracted by using 50 mM citrate from soil samples by following the standard protocol[23].

Statistical analysis

One-way analysis of variance (ANOVA) was carried out for comparing statistical significance of soil properties under the sub land use systems with SPSS 16 for Windows (SPSS Inc., Chicago, USA). The Pearson's correlation coefficient was used to determine the strength of different soil quality properties. To assess the relationships between the observed 21 variables, principal component analysis (PCA) was performed through the varimax rotation procedure. The principal components of high eigen values (>1) and explain at least 5% of the variation in the data were selected and subjected to the further selection of indicators[24]. Within each PC, only highly weighted factors were retained for minimum data set. The selected observations were transformed in numerical scores (ranged 0–1) and weighted additive approach was used to integrate them into selected variables[25].

Soil quality index (SQI)

The per cent variation of each PC to total percent variation gave the weighted factor for each selected indicator from the PCA[25]. The SQI is computed by integrating score (S) and weight factor (W) of each indicator using the following equation:

$$SQI = \sum_{i-1}^{n} (Wi \times Si)$$

Soil with higher index score indicates better performance of soil quality indicators.

Results

Soil physicochemical properties

The soil pH is slightly acid to neutral (pH of 6.4 to 6.9) among the different land use systems. The variation within the subsystem is not significant (Table 1). These soils are nonsaline with EC of 0.09 to 0.23 dS m^{-1} and shows significantly lower EC for bamboo and poplar-based forestry systems (0.09 dS m^{-1}) however higher at eucalyptus-based forestry system (0.23 dS m^{-1}). The sand, silt and clay contents were significantly varied between sub land use systems and varied from loamy sand to sandy loam in texture (Table 1).

Among land use systems, the increasing order of organic carbon content was observed for agri-horticulture system followed by forestry > horticulture > agroforestry > agriculture > eroded land (Table 2). The highest soil organic carbon content of 0.83 % was recorded in mango based agri-horticulture system and minimum in eroded lands. The available nitrogen

Table 1 — Effect of different land use systems on physicochemical properties of soils in sub montane Punjab India

Land use	Sub land use	pH	EC (dS m^{-1})	Textural class	Sand (%)	Silt (%)	Clay (%)
Forestry	Bamboo	6.6±0.13	0.09±0.01	Loamy sand	83.2±0.05	9.3±0.04	7.5±0.06
	Eucalyptus	6.6±0.16	0.23±0.03	Sandy loam	76.7±1.9	12.7±1.9	10.6±0.09
	Poplar	6.5±0.06	0.09±0.01	Sandy loam	77.7±1.2	11.8±1.1	10.5±0.1
	Mean	6.6±0.11	0.14±0.02	Sandy loam	79.2±1.2	11.3±1.1	9.4±0.5
Agro forestry	Dek based	6.8±0.09	0.15±0.04	Sandy loam	80.4±0.02	9.2±0.03	10.4±0.01
	Eucalyptus	6.9±0.12	0.19±0.03	Loamy sand	84.6±0.07	4.1±0.06	11.3±0.05
	Mean	6.9±0.11	0.17±0.03	Loamy sand	82.5±0.04	6.6±0.05	10.9±0.03
Horticulture	Kinnow	6.9±0.25	0.14±0.05	Loamy sand	84.1±0.01	5.3±0.4	10.6±0.07
	Mango	6.8±0.32	0.13±0.03	Loamy sand	82.7±0.04	6.9±0.08	10.5±0.04
	Mean	6.9±0.28	0.13±0.04	Loamy sand	83.4±0.03	6.1±0.06	10.6±0.05
Agri-horticulture	Mango	6.6±0.27	0.22±0.05	Loamy sand	83.1±0.10	7.4±0.7	9.5±0.6
Agriculture	Maize – wheat	6.4±0.08	0.19±0.02	Sandy loam	79.3±3.70	11.2±1.4	10.8±1.1
Eroded land	Uncultivated	6.4±0.29	0.10±0.02	Loamy sand	84.5±1.60	7.6±1.4	8.0±0.3
LSD (*P*=0.05)	Sub land use	NS	0.05		3.9	2.3	1.2
	Land use	NS	0.03		2.6	2.8	1.4

Table 2 — Effect of different land use systems on soil organic carbon, soil available NPK content and DTPA extractable micronutrients content in sub montane Punjab India

Land use system	Sub system	OC (%)	Avail N	Avail P	Avail K	DTPA extractable micronutrients (mg kg^{-1})			
				(kg ha^{-1})		Mn	Fe	Cu	Zn
Forestry	Bamboo	0.62±0.11	360±16.7	32.6±0.03	119±21.5	20.1±7.0	28.7±6.1	0.70±0.05	0.89±0.09
	Eucalyptus	0.61±0.04	347±15.1	32.2±0.15	226±36.2	20.7±6.6	28.6±6.5	0.97±0.41	0.90±0.24
	Poplar	0.58±0.03	345±22.6	32.2±0.37	185±70.0	20.0±5.9	34.0±6.6	0.51±0.05	0.90±0.20
	Mean	0.61±0.03	351±22.6	32.3±0.37	177±70.0	203±5.9	30.3±6.6	0.73±0.05	0.90±0.20
Agro forestry	Dek based	0.50±0.06	339±12.8	31.2±0.32	119±29.0	16.3±7.8	31.2±8.9	0.80±0.06	0.97±0.07
	Eucalyptus	0.60±0.05	359±14.6	31.9±0.13	155±20.8	19.7±8.1	26.3±7.5	0.63±0.09	0.76±0.13
	Mean	0.55±0.03	349±22.6	31.6±0.37	137±70.0	18.0±5.9	28.8±6.6	0.51±0.05	0.90±0.20
Horticulture	Kinnow	0.56±0.07	343±4.2	31.0±0.32	124±25.2	16.1±6.5	23.5±8.2	0.57±0.20	0.93±0.26
	Mango	0.61±0.11	348±11.6	31.5±0.44	114±32.2	18.6±7.4	31.0±8.1	0.83±0.09	0.78±0.09
	Mean	0.59±0.09	347±7.8	31.1±0.38	119±28.7	17.4±7.0	27.3±8.2	0.70±0.15	0.86±0.18
Agri-horticulture	Mango	0.83±0.03	406±48.2	32.5±0.10	192±21.4	21.2±8.9	34.2±6.0	1.01±0.43	1.15±0.37
Agriculture	Maize – wheat	0.38±0.03	322±18.2	30.4±0.98	112±13.9	17.2±6.7	17.1±7.7	0.69±0.08	0.77±0.14
Eroded land	Uncultivated	0.14±0.02	86±17.8	29.3±0.08	65±13.8	10.3±3.4	12.1±4.2	0.34±0.10	0.76±0.14
LSD (*P*=0.05)	Sub land use	0.12	60.1	0.86	53.1	NS	5.60	NS	NS
	Land use	0.11	66.2	NS	48.1	NS	5.2	NS	NS

content varied from 86 to 406 kg ha^{-1} and had significant variation among land use and sub land use systems (Table 2). The maximum available phosphorus content was 32.6 kg ha^{-1} in bamboo-based forestry system however it was least 29.3 kg ha^{-1} in eroded lands. The potassium content among main land use systems was recorded in order as agri-horticulture > forestry > agroforestry > horticulture > agriculture and eroded lands. The contents of DTPA extractable micronutrients were 10.3-21.1 mg kg^{-1} for manganese (Mn), 12.1-34.5 mg kg^{-1} for iron (Fe), 0.34-1.01 mg kg^{-1} for copper (Cu) and 0.76-1.15 mg kg^{-1} for zinc (Zn) under different land use systems. The mango based agri-horticulture system had high amounts of DTPA-Mn (21.1 mg kg^{-1}), DTPA-Cu (1.15 mg kg^{-1}) and DTPA-Zn (1.15 mg kg^{-1}) as compared to the other sub systems. The high DTPA-Fe was highest (34.5 mg kg^{-1}) in poplar-based forestry system (Table 2).

Soil biochemical properties

The high dehydrogenase activity (DHA) was observed in mango agri-horticulture system (12.8 µg TPF g^{-1} h^{-1}) and low in eroded land use system (7.4 µg TPF g^{-1} h^{-1}). The acid phosphatase varied from 22.3 µg pNP g^{-1} h^{-1} to 33.0 µg pNP g^{-1} h^{-1} but highest was in mango based agri-horticulture based systems (33.0 µg pNP g^{-1} h^{-1}) and lowest in eroded lands (22.3 µg pNP g^{-1} h^{-1}). The alkaline phosphatase under different land use systems varied from 43.4 to 60.1 µg pNP g^{-1} h^{-1} with higher value in mango based agri-horticulture system. The urease in soil was high (4.77 µg NH_4-N g^{-1} soil min^{-1}) under mango based agri-horticulture system and low in maize – wheat (4.25 µg NH_4-N g^{-1} soil min^{-1}) and eroded system (3.31 µg NH_4-N g^{-1} soil min^{-1}). The soil basal respiration is significantly varied from 0.13 to 0.30 µg CO_2g^{-1} soil h^{-1} among the different land use systems with high values in agri-horticulture system. Mango based system had the soil respiration of 0.30 µg CO_2 g^{-1} soil h^{-1}. The maize-wheat system and eroded land use systems showed low soil respiration values of 0.18 µg CO_2 g^{-1} soil h^{-1} and 0.13 µg CO_2 g^{-1} soil h^{-1}, respectively (Table 3). Eucalyptus based forestry system has recorded highest MBC content of 242.6 µg g^{-1} soil as compared to poplar based (230.9 µg g^{-1} soil) and mango based systems (221.1 µg g^{-1} soil). The total extractable glomalin related to soil protein content (TGSP) and easily extractable glomalin protein content (EGSP) varied from 8.68 to 30.6 g kg^{-1} and 1.40 to 25.1 g kg^{-1}, respectively. TGSP and EGSP content was significantly high in mango based agri-horticulture system (30.6 g kg^{-1} and 25.1 g kg^{-1}). The low TGSP and EGSP contents were noticed in eroded land use system with the content of 16.3 and 1.40 g kg^{-1}, respectively.

Correlation analysis

The correlation analysis revealed that the organic carbon had significant (P=0.01) positive correlations with DHA (r=0.85), alkaline phosphatase (r=0.89), urease (r=0.87) and TGSP (r=0.85). Among biochemical

Table 3 — Effect of different land use systems on biochemical properties of soil in sub montane Punjab India

Land use system	Sub system	DHA	Acid P	Alk P	Urease	BSR	MBC	TGRSP	EEGRSP
Forestry	Bamboo	12.7±2.1	34.5±11.6	58.7±11.7	4.31±0.4	0.17±0.002	113.9±0.9	27.5±3.7	22.0±1.7
	Eucalyptus	12.0±1.8	28.5±13.6	56.5±13.5	4.49±0.4	0.27±0.005	242.6±22.3	23.3±1.5	13.2±0.9
	Poplar	12.4±1.9	31.1±10.8	58.2±11.4	4.27±0.1	0.22±0.001	187.8±23.3	19.3±1.0	5.71±1.7
	Mean	12.4±1.9	31.4±12.0	57.9±12.2	4.36±0.3	0.22±0.003	181.4±15.5	23.4±2.1	13.6±1.4
Agro forestry	Dek based	11.4±1.4	27.5±11.5	54.7±5.0	4.63±0.3	0.16±0.002	230.9±0.1	15.4±0.7	10.7±1.7
	Eucalyptus	12.1±1.5	29.7±13.0	58.8±12.0	4.42±0.3	0.20±0.003	74.1±1.9	19.8±1.2	10.7±1.2
	Mean	11.8±1.5	28.6±12.2	56.8±9.0	4.53±0.3	0.18±0.003	152.5±1.0	17.6±1.0	10.7±1.5
Horticulture	Kinnow	10.8±1.8	27.4±13.7	57.9±12.0	4.14±0.7	0.23±0.005	67.4±8.5	15.7±5.1	9.14±0.4
	Mango	10.4±1.1	27.5±13.3	57.3±8.6	4.39±0.3	0.21±0.004	77.5±4.7	16.7±5.1	9.06±1.4
	Mean	10.6±1.9	27.5±13.5	57.6±10.3	4.26±0.5	0.22±0.005	72.5±6.6	17.7±5.1	9.10±0.9
Agri-horticulture	Mango	12.8±2.5	33.0±11.7	60.1±12.2	4.77±0.4	0.30±0.006	221.1±11.2	30.6±0.7	25.1±1.7
Agriculture	Maize – wheat	10.2±1.6	26.7±13.7	55.8±10.3	4.25±0.1	0.18±0.001	56.2±7.4	16.3±0.3	8.63±5.0
Eroded land	Uncultivated	7.4±1.1	22.3±14.3	43.4±8.3	3.31±0.3	0.13±0.002	46.5±3.1	8.7±2.2	1.40±0.3
LSD (*P*=0.05)	Sub land use	2.1	NS	NS	0.64	0.008	37.5	9.25	4.82
	Land use	1.0	NS	NS	0.55	0.008	29.9	8.76	4.66

DHA: Dehydrogenase Activity (µg TPF g^{-1} h^{-1}); AlkP: Alkaline Phosphatase (µg pNP g^{-1} h^{-1}); Acid P: Acid Phosphatase (µg pNP g^{-1} h^{-1}); Urease (µg NH_4-N g^{-1} soil min^{-1}); BSR: Basal Soil Respiration (µg CO_2 g^{-1} soil h^{-1}); MBC: Microbial biomass carbon (µg g^{-1} soil); TGSP: Total extractable glomalin related soil protein (g kg^{-1}); EGSP: Easily extractable glomalin related soil protein (g kg^{-1})

Table 4 — Correlation among various soil properties in sub montane Punjab India

	pH	EC	OC	N	P	K	Mn	Fe	Cu	Zn	DHA	AcP	AlP	Ure	BSR	MBC	TGSP
EC	0.3																
OC	0.48	0.59															
N	0.47	0.42	0.90**														
P	0.29	0.36	0.87**	0.83**													
K	0.07	0.67*	0.70*	0.63	0.75*												
Mn	0.22	0.45	0.87**	0.90**	0.94**	0.80**											
Fe	0.38	0.28	0.83**	0.79**	0.87**	0.66*	0.79**										
Cu	0.22	0.73*	0.77**	0.70*	0.61	0.6	0.69*	0.6									
Zn	0.1	0.42	0.65*	0.5	0.52	0.51	0.41	0.61	0.56								
DHA	0.31	0.38	0.85**	0.90**	0.96**	0.75*	0.93**	0.83**	0.58	0.57							
AcP	0.14	0.15	0.78**	0.77**	0.92**	0.55	0.85**	0.74*	0.46	0.54	0.92**						
AlP	0.45	0.34	0.89**	0.98**	0.84**	0.61	0.90**	0.75*	0.58	0.43	0.89**	0.81**					
Ure	0.42	0.58	0.87**	0.93**	0.77**	0.65*	0.83**	0.81**	0.84**	0.58	0.84**	0.67*	0.84**				
BSR	0.18	0.72*	0.82**	0.65*	0.64*	0.84**	0.70*	0.58	0.68*	0.64*	0.64	0.48	0.64*	0.62			
MBC	−0.01	0.49	0.52	0.45	0.59	0.73*	0.51	0.71*	0.63*	0.73*	0.61	0.43	0.33	0.64*	0.53		
TGSP	0.06	0.45	0.85**	0.74*	0.89**	0.67*	0.87**	0.67*	0.70*	0.63	0.85**	0.91**	0.75*	0.71*	0.68*	0.52	
EGSP	0.13	0.43	0.77**	0.66*	0.73*	0.43	0.68*	0.54	0.71*	0.69*	0.72*	0.82**	0.63	0.67*	0.53	0.44	0.93**

* Correlation is significant at the 0.05 level (2-tailed).** Correlation is significant at the 0.01 level (2-tailed).

EC: Electrical Conductivity; OC: Organic carbon; N: Available Nitrogen; P: Available phosphorus; K: Available potassium; Fe: DTPA extractable iron; Mn: DTPA extractable manganese; Cu: DTPA extractable copper; Zn: DTPA extractable zinc; DHA: Dehydrogenase Activity (µg TPF g^{-1} h^{-1}); AlkP: Alkaline Phosphatase (µg pNP g^{-1} h^{-1}); Acid P: Acid Phosphatase (µg pNP g^{-1} h^{-1}); Urease (µg NH_4-N g^{-1} soil min^{-1}); BSR: Basal Soil Respiration (µg CO_2 g^{-1} soil h^{-1}); MBC: Microbial biomass carbon (µgg^{-1} soil); TGSP: Total extractable glomalin related soil protein (g kg^{-1}); EGSP: Easily extractable glomalin related soil protein (g kg^{-1})

properties, DHA was significantly correlated (P=0.01) with acid phosphatase (r=0.92), alkaline phosphatase (r=0.89), urease (r=0.84) TGSP (r=0.85) and EGSP (r=0.72). The acid phosphatase content was significantly correlated (P=0.01) with alkaline phosphatase (r=0.84), urease (r=0.64) and total extractable glomalin (r=0.75). The alkaline phosphatase was significantly correlated (P=0.05) with urease (r=0.84), basal soil respiration (r=0.64) and TGSP (r=0.75). The urease content was significantly correlated (P=0.05) with MBC (r=0.64), TGSP (r=0.71) and EGSP (r=0.67). The TGSP was significantly correlated (P=0.01) with EGSP (r=0.93) (Table 4).

PCA & SQI

The PCA determined the sensitivity pattern of all measured soil parameters along with the factor loading and eigen value of each variable (Fig. 3). In PCA, PCs with eigen value >1 were considered as effective component for changes in soil quality. Out of 21 measured soil properties, only 5 components or properties have eigen value more than 1 and cumulatively explained 94.2% of the variance. The weightage of selected soil properties was derived by dividing percent variation in each PC to that of percent cumulative variation for all the selected PCs. The weight of each PC on the basis of percent variance to total variance varied from 0.57 to 0.05 and showed the following trend: PC1 (0.57) > PC2 (0.19) > PC3 (0.08)> PC4 (0.05) > PC5 (0.05). The most influential variables for PC1 was organic carbon, EC for PC2, TGSP for PC3, MBC for PC4 and Zn for PC5 on the basis of eigen vector weighted value or factor loading (Table 5). The values of SQI among

Table 5 — Principal component and loading factors related to soil properties

	Loading values	Contribution of variables (%)	Loading values	Contribution of variables (%)	Loading values	Contribution of variables (%)	Loading values	Contribution of variables (%)	Loading values	Contribution of variables (%)
pH	0.33	0.88	−0.27	4.41	0.81	7.29	0.02	0.06	0.29	10.13
EC	0.57	2.72	0.63	23.25	0.38	10.32	0.18	3.90	−0.20	4.71
OC	0.96	7.61	−0.04	0.11	0.17	2.03	0.11	1.35	0.02	0.03
N	0.91	6.90	−0.24	3.53	0.20	3.02	−0.01	0.00	−0.02	0.05
P	0.93	7.18	−0.22	2.92	−0.13	1.23	−0.13	1.89	−0.06	0.41
K	0.80	5.29	0.34	6.76	−0.04	0.14	−0.35	14.11	−0.31	11.87
Mn	0.93	7.19	−0.17	1.72	−0.04	0.12	−0.10	1.17	−0.27	9.10
Fe	0.86	6.07	−0.12	0.86	0.01	0.00	−0.34	13.16	0.27	8.81
Cu	0.79	5.21	0.35	7.30	0.14	1.34	0.24	6.70	0.03	0.10
Zn	0.68	3.85	0.34	6.84	−0.23	3.94	0.11	1.47	0.48	27.69
DHA	0.94	7.25	−0.23	3.12	−0.09	0.62	−0.14	2.27	0.00	0.00
AcP	0.84	5.86	−0.39	9.05	−0.34	8.51	0.06	0.48	0.00	0.00
AlP	0.88	6.40	−0.36	7.68	0.17	2.21	−0.01	0.01	−0.13	1.90
Ure	0.91	6.85	0.00	0.00	0.21	3.17	−0.01	0.01	0.13	1.94
BSR	0.79	5.10	0.38	8.44	0.10	0.70	0.00	0.00	−0.26	7.88
MBC	0.67	3.70	0.48	13.74	−0.22	3.48	−0.37	15.32	0.32	12.21
TGSP	0.90	6.67	−0.06	0.20	−0.31	16.98	0.25	7.37	−0.12	1.64
EGSP	0.80	5.26	−0.04	0.07	−0.26	4.91	0.52	30.72	0.11	1.52
Eigen value		12.11		1.68		1.38		1.12		1.02
Variability (%)		57.26		19.35		7.68		5.84		5.01
Cumulative %		57.26		76.61		84.30		90.14		94.15

EC: Electrical Conductivity; OC: Organic carbon; N: Available Nitrogen; P: Available phosphorus; K: Available potassium; Fe: DTPA extractable iron; Mn: DTPA extractable manganese; Cu: DTPA extractable copper; Zn: DTPA extractable zinc; DHA: Dehydrogenase Activity (μg TPF g^{-1} h^{-1}); AlkP: Alkaline Phosphatase (μg pNP g^{-1} h^{-1}); Acid P: Acid Phosphatase (μg pNP g^{-1} h^{-1}); Urease (μg NH_4-N g^{-1} soil min^{-1}); BSR: Basal Soil Respiration (μg CO_2 g^{-1} soil h^{-1}); MBC: Microbial biomass carbon (μg g^{-1} soil); TGSP: Total extractable glomalin related soil protein (g kg^{-1}); EGSP: Easily extractable glomalin related soil protein (g kg^{-1})

Table 6 — Effect of different land use systems on soil quality index and the individual contribution of each indicators

Land use	Organic carbon	Electrical Conductivity	Total extractable glomalin related soil protein	Microbial biomass carbon	DTPA-Zn	Soil quality index
Agri-horticulture	0.53	0.08	0.05	0.05	0.03	0.74
Forestry	0.61	0.09	0.05	0.05	0.03	0.83
Horticulture	0.43	0.15	0.04	0.04	0.03	0.69
Agroforestry	0.48	0.12	0.05	0.04	0.03	0.72
Agriculture	0.37	0.09	0.05	0.04	0.03	0.58
Eroded	0.33	0.08	0.04	0.04	0.03	0.52
Average (%)	45.8	10.2	4.6	4.4	2.7	

land use system was maximum under forestry (0.83%), followed by agri-horticulture (0.74), agroforestry (0.72), horticulture (0.69), agriculture (0.58) and eroded system (0.52) respectively (Table 6). The order of contribution of the selected indicators to SQI was 45.9% for OC, 10.2% for EC, 4.6% for TG, 4.4% for MBC and 2.7% for Zn.

Discussion

Soil physico-chemical properties

The soils under study are slightly acid (pH-6.4) to neutral (pH6.9) under the different land use systems of submontane Punjab. The soil texture plays an important role in the occurrence of various nutrients as well as in microbial activity in soils[26]. The sand, silt and clay contents vary significantly among the various sub land use systems with the high sand (84.6%) and silt content (12.7%) with 11.3 % of clay under eucalyptus-based agroforestry system. The similar observations were also recorded in previous studies in which it has been reported that forests and cultivated based land use systems have more clay content than uncultivated and pasture-based systems[27].

Among land use systems, the high organic carbon content (0.8%) is recorded under agri-horticulture system over forestry > horticulture > agroforestry > agriculture > eroded land. The high soil organic carbon under agri-horticulture system may be due to addition of FYM and leaf litter and their differential rate of decomposition[28]. The cultivated land (0.38%) use registered low OC (0.61%) due to intense cultivation. Intense cultivation reduced soil carbon content and changed the distribution and stability of soil aggregates[29]. The minimum content of soil organic carbon was observed in eroded land (0.14%) due to loss of carbon with runoff and soil erosion. The available nitrogen content in soil varies significantly among land uses and sub land use systems. The decomposition rate of soil organic carbon and nitrogen mineralization rate are affected by the variations in soil microclimate, soil conditions, land use systems and land management practices such as soil moisture content and agronomic measures, have impact on soil nitrogen mineralization and transformation[30]. The optimal configuration of land use improved the nitrogen patterns in soil. The available phosphorus content is high in bamboo-based forestry system due to high soil organic carbon and in agri-horticulture system due to addition of phosphatic fertilizers along with FYM. The low phosphorus content in eroded lands is due to soil erosion. The potassium content among main land use systems shows declining order as: agri-horticulture > forestry > agroforestry > horticulture > agriculture > eroded lands. The low potassium content in eroded land (65 kg ha^{-1}) is due to erosion/runoff and in cultivated land (112 kg ha^{-1}) as compared to other systems[31]. Among micronutrients, only DTPA-Fe showed significant variations among different land use systems. The mango based agri-horticulture system has high DTPA-Mn, DTPA-Cu and DTPA-Zn than other land use systems. This trend for micronutrients observed is similar to that of organic carbon in binding of nutrients. The availability of micronutrients increases with organic matter as it protects from precipitation of micronutrients and supply soluble chelating agents[32].

Soil biochemical properties

The dehydrogenase activity (indicator of microbial redox systems and measure of microbial oxidative activities) is high in agri-horticulture system (Fig. 1). The cultivation of fodder crops along with the

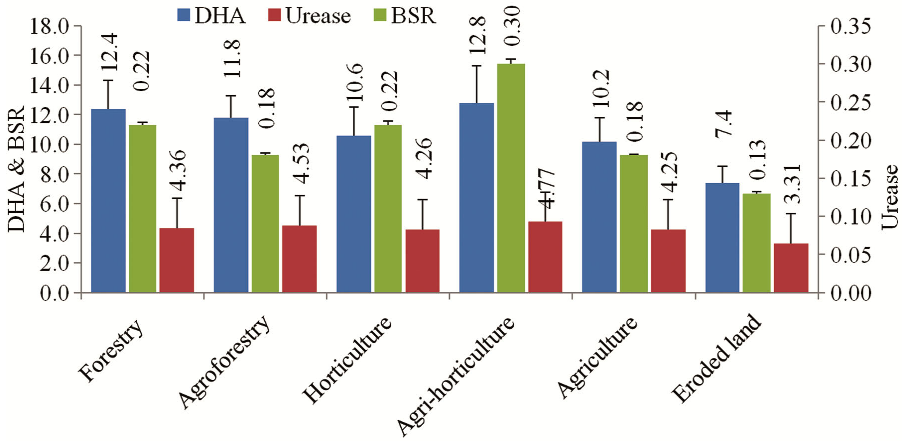

Fig. 1 — Effect of different land use systems on dehydrogenase, basal soil respiration and urease activity of soil in sub montane Punjab India

horticultural crops can lead to higher root biomass accumulation in soils in the form of organic matter thereby, increasing the microbial activity in soils. Literature studies reported high DHA in agricultural cropping system than the other land use systems due to low carbon content which led to higher oxidation of organic matter in clayey soils of Brazil[33]. Phosphatase activity in soils is directly related to organic phosphorus levels in soils. The high acid phosphatase content and alkaline phosphatase content were observed in mango based agri-horticulture based systems. There is no significant variation in acid phosphatase content and alkaline phosphatase content among different land use systems. Enzyme urease is responsible for the urea breakdown into CO_2 and NH_3 and important for maintaining the N_2-economy of soil[34]. The urease content is high in mango based agri-horticulture system (4.77 µg NH_4-N g^{-1} soil min^{-1}) and low in eroded system (3.31 µg NH_4-N g^{-1} soil min^{-1}) which might be due to high soil organic carbon content[35]. Basal Soil respiration (BSR) is a measure of carbon dioxide (CO_2) released from the soil during decomposition of soil organic matter (SOM) by soil microbes and respiration from plant roots and soil fauna. Among different land use systems high value is recorded in agri-horticulture systems and low in maize-wheat system and eroded land use systems due to depletion of readily decomposable substrates for microorganism and higher ratio of respiration to biomass as metabolic quotient. Another study reported increase in soil respiration by 3–22 per cent following conversion of grassland to woodland. The conversion of forest to cropland leads to 33 per cent decline in soil respiration[36]. Eucalyptus based forestry system has high MBC content and maize – wheat system as well as eroded land with low MBC contents (Fig. 2). Also, forests have been found to possess high soil respiration as compared to other land use systems due to relatively dense structure of plants and the continuous deposition of organic matter through leaf litter and fine roots[37]. The high MBC contents under forestry-based system is observed due to rapid oxidation of organic carbon over other systems[38]. In agricultural land use systems, the absence of fresh organic matter inputs limits the energy substrate (C) essential for microbes and results in their poor growth[39]. The TGSP (30.6 g kg^{-1}) and EGSP (25.1 g kg^{-1}) is significantly high in mango based agri-horticulture system but low in eroded land use system (Fig. 2). The glomalin related soil protein (GRSP) is related to soil protein and affected by agricultural practices as well as the organic matter content in the soils.

Correlation analysis

The soil organic carbon showed significant coefficient correlation (P=0.01) with DHA, alkaline phosphatase, urease and TGSP which might be due the variations in soil microbial activities under different land use management activities and changes in cropping systems and soil amendments under different land use systems[5]. The different enzymes *i.e.* DHA, acid phosphatase, alkaline phosphatase, urease TGSP and EGSP also showed significant correlation (P=0.05) among themselves. The organic carbon content in soil stimulated the soil enzymatic activities by improving the availability of substrates for soil microbial activity. The soil glomalin content also showed positive correlation with soil organic carbon and other enzymes in the soil, because initial phases of organic matter decomposition in soil increased the soil fungal biomass along with the soil enzymatic

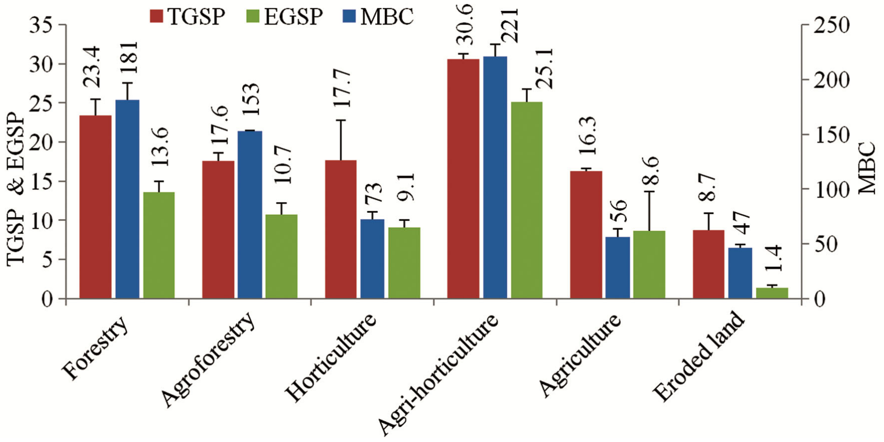

Fig. 2 — Effect of different land use systems on dehydrogenase, basal soil respiration and urease activity of soil in sub montane Punjab India

activity[40]. Moreover, alteration in land-use type initiated changes in soil properties, affected the composition of soil microbial communities and activities of soil microbial enzymes[41].

PCA analysis and SQI

PCA described the overall sensitivity pattern of soil parameters. The principal components (PCs) with high eigen values were considered to represent the variations in soil properties. Five components with eigen value more than 1 showed the following trend: PC1 (0.57) > PC2 (0.19) > PC3 (0.08)> PC4 (0.06)> PC5 (0.05). The eigen values as well as per cent variability decreased with the increase in PC. Among, these 5 components contributed 94.2 % of total variations in soil fertility. The most influential variables for PC1 was organic carbon, EC for PC2, TGSP for PC3, MBC for PC4 and Zn for PC5 on the basis of eigen vector weight value or factor loading. The SQI results shows that forest soils have SQI of 0.83% followed by agri-horticulture (0.74%), agroforestry (0.72%), horticulture (0.69%), agriculture (0.58%) and bare (0.52%), respectively. The order of contribution of the selected indicators to SQI was 45.9% for OC, 10.2% for EC, 4.6% for TG, 4.4% for MBC and 2.7% for Zn. These parameters were considered as potential indicators of soil quality in Indian lower Himalayas. Soil organic carbon was the most imperative soil quality indicator in PC1, which monitors soil physical, chemical, and biological properties in soil. EC was the second important soil quality indicator because it acts as a surrogate measure of salt concentration, organic matter, cation-exchange capacity, water-holding capacity and drainage conditions[42]. The soil EC has also been associated with nitrate level in soil and other selected soil nutrients (P, K, Ca, Mg, Mn, Zn, and Cu). The microorganisms' activities in soil are also associated with soil EC and decline with increase in soil EC[42]. In PC3, TGSP was a better indicator of soil quality because high glomalin contents is related to less soil disturbance which stabilizes soil aggregates and thus, enhances soil structural properties and soil carbon storage[43]. Glomalin is a fungal protein which is exuded by the living fungus and operationally quantified as glomalin-related soil protein. Glomalin is only released by an AMF into the soil environment and is a gluelike stable compound, insoluble in water and resistant to heat degradation[44]. Glomalin concentrations in soil were more than 100 mg g^{-1} in tropical forest soils and less than 1.0 mg g^{-1} in desert ecosystems[44]. In PC4, available MBC was retained as quality indicator, because it closely related to soil organic matter content. MBC is strongly influenced by management practices and system perturbations[45] and it provides an indication of soil's ability to store and recycle nutrients and energy. In PC5, Zn was retained due to undulating topographical constraints and poor management practices under different land use systems. The high level of Zn in forest-based land use systems was associated with regular addition of organic materials[27]. The loading plot value (Fig. 3) shows the

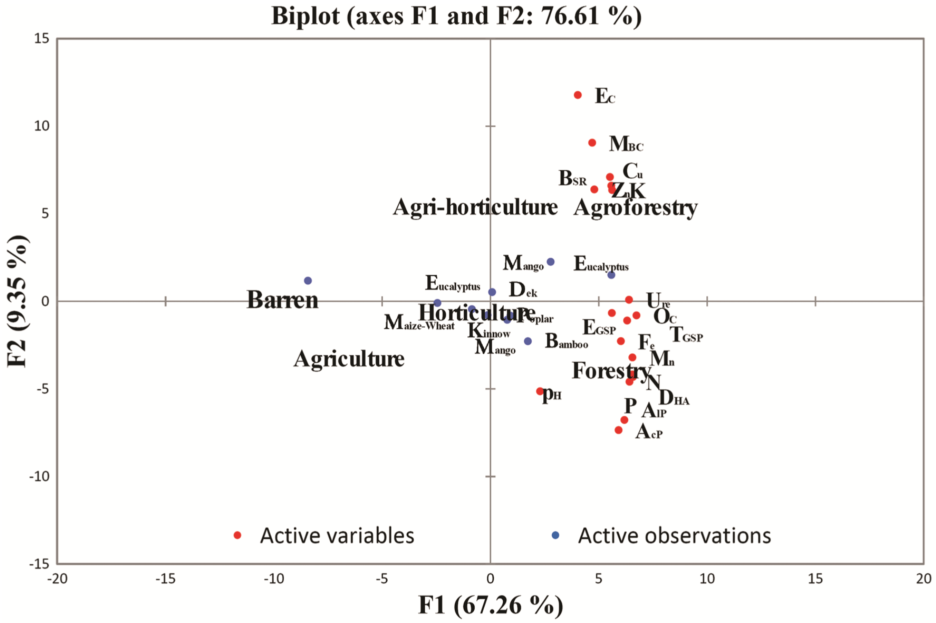

Fig. 3 — Principal component analysis for sub systems and soil properties

position of different land use systems enforced soils in the orthogonal space defined by PC1 and PC2. The PCs clearly separated the rainfed agriculture and forest, mixed forest samples from afforestation and non arable lands samples. This contribution of OC toward SQI was highest under the land use forestry system (0.61) followed by agri-horticulture (0.53), agroforestry (0.48), horticulture (0.43), agriculture (0.37) and bare (0.34). For EC the maximum contribution toward SQI was observed under horticulture (0.09) and minimum under bare (0.08). TG contributed maximum to SQI under land under forestry (0.050) and minimum under the eroded (0.044). The better SQI under the land use forest is attributed to the high soil organic matter status. It is well known that SOM is one of the best indicators responsible with regard to maintaining better soil health/quality in term of nutrient cycling, carbon sequestration, and crop production in the rainfed region of the country. The agroforestry, agri-horticulture, and grassland systems have the potential to reduce both the runoff and erosion, and maintain better soil organic matter, which in return would help in improving the fertility status of the soil[37]. The lower values of SQI under eroded land use system was due to low organic matter content in soil which might be attributed to less vegetation and plant residue incorporation. Previous studies also observed the same sequence for SQI as: forest (0.80) > grasses (0.79) > horticulture (0.78) > cultivated (0.75) > bare (0.67)[8].

Conclusion

Among different systems, the soil quality index was maximum under forestry system followed by agri-horticulture, agroforestry, horticulture, agriculture and barren lands, respectively. The organic carbon, EC, TGSP, MBC and Zn were observed to be robust soil quality indicators for soil quality under different land use systems. Eucalyptus based forestry; mango based agri-horticulture system served as a better system for soil health. These screened indicators may be used by the researchers for real time monitoring of soil health and ecological processes in future under various land use systems in submontane Punjab, India

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Conflict of interest

All authors declare no conflict of interest.

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